

# **The Oil Security Metrics Model:**

## **A Tool for Evaluating the Prospective Oil Security Benefits of DOE's Energy Efficiency and Renewable Energy R&D Programs**

**May 2006**

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## **THE OIL SECURITY METRICS MODEL**

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OF DOE'S ENERGY EFFICIENCY AND RENEWABLE ENERGY  
R&D PROGRAMS

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## EXECUTIVE SUMMARY

### ES.1 PURPOSE

Energy technology R&D is a cornerstone of U.S. energy policy. Understanding the potential for energy technology R&D to solve the nation's energy problems is critical to formulating a successful R&D program. In light of this, the U.S. Congress requested the National Research Council (NRC) to undertake both retrospective and prospective assessments of the Department of Energy's (DOE's) Energy Efficiency and Fossil Energy Research programs (NRC, 2001; NRC, 2005)<sup>1</sup>. In 2004, the NRC Committee on Prospective Benefits of DOE's Energy Efficiency and Fossil Energy R&D Programs published a report recommending a new framework and principles for prospective benefits assessment. The Committee explicitly deferred the issue of estimating security benefits to future work. Recognizing the need for a rigorous framework for assessing the energy security benefits of its R&D programs, the DOE's Office of Energy Efficiency and Renewable Energy (EERE) developed a framework and approach for defining energy security metrics for R&D programs to use in gauging the energy security benefits of their programs (Lee, 2005).

This report describes methods for estimating the prospective oil security benefits of EERE's R&D programs that are consistent with the methodologies of the NRC (2005) Committee and that build on Lee's (2005) framework. Its objective is to define and implement a method that makes use of the NRC's typology of prospective benefits and methodological framework, satisfies the NRC's criteria for prospective benefits evaluation, and permits measurement of that portion of the prospective energy security benefits of EERE's R&D portfolio related to oil. While the Oil Security Metrics (OSM) methodology described in this report has been specifically developed to estimate the prospective oil security benefits of DOE's R&D programs, it is also applicable to other strategies and policies aimed at changing U.S. petroleum demand.

### ES.2 DEFINITIONS

The central question for developing oil security metrics is defining the phenomena to be measured. This analysis begins with the definitions proposed by the National Research Council's Committee on Benefits of DOE R&D on Energy Efficiency and Renewable Energy (NRC, 2001). The Committee divided all benefits into three categories: (1) economic, (2) environmental, and (3) security. The Committee's definitions of economic and security benefits are the following (emphasis added).

**“Economic net benefits** are based on changes in the total market value of goods and services that can be produced in the U.S. economy under normal conditions, where ‘normal’ refers to conditions absent energy disruptions or other energy shocks.” (NRC, 2001, p. 15)

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<sup>1</sup> “The Congress continued to express its interest in R&D benefits assessment by providing funds for the NRC to build on the retrospective methodology to develop a methodology for assessing prospective benefits.” (NRC, 2005, p. ES-2)

**“Security net benefits** are based on changes in the probability or severity of abnormal energy-related events that would adversely impact the overall economy, public health and safety, or the environment. Historically, these benefits arose in terms of national security issues, i.e., they were benefits that assured energy resources required for a military operation or a war effort. Subsequently, they focused on dependence upon imported oil and the vulnerability to interdiction of supply or cartel pricing as a political weapon. More recently, the economic disruptions of rapid international price fluctuations from any cause have been emphasized.” (NRC, 2001, p. 15)

The Committee emphasized that benefits should be estimated net of all public and private costs. In this report benefits and net benefits will be used to describe benefits net of all costs; gross benefits will refer to benefits from which all public and private costs have not been subtracted.

This report deals only with oil security net benefits. Security benefits associated with other primary and final energy forms are not considered in this report (see, e.g., Lee, 2005 for a comprehensive review of energy security benefits). Not only does this exclude issues related to the electricity grid, for example, but questions of refinery and petroleum product infrastructure security, as well.

Like the most recent NRC (2005) report, the Oil Security Metrics Model is concerned with potential future, or prospective, rather than past or retrospective benefits. Because the future is uncertain, and particularly so with respect to “abnormal” market conditions, the OSM simulates a large number of possible future oil market scenarios. The result is a distribution of prospective oil security net benefits. It is often convenient to describe the results in terms of expected, or mean, net benefits.

Finally, the categories for which quantitative measures, or metrics, are developed can be divided into those that can be readily measured in constant, present value dollars and those for which monetary metrics are either not appropriate or highly controversial. The benefits that can be measured monetarily are comprised of, (1) transfer of wealth, (2) economic surplus losses, and (3) macroeconomic disruption costs. Each of these components is defined in detail below. Non-monetary costs include the political, strategic and military risks associated with oil insecurity.

The categories of benefits discussed above and those that are covered in this report are illustrated in Figure ES-1.

ENERGY SECURITY GROSS BENEFITS		
ENERGY SECURITY NET BENEFITS		PUBLIC AND PRIVATE COSTS
NON-OIL SECURITY NET BENEFITS		
OIL SECURITY NET BENEFITS		DIFFERENCE BETWEEN OIL SECURITY GROSS AND NET BENEFITS
MONETARY METRICS (PV, 2004 \$)	NON-MONETARY METRICS	
1. Transfer of Wealth 2. Economic Surplus Losses 3. Macroeconomic Disruption Costs	Political Risk Strategic Risk Military Costs	

**Figure ES-1. Diagrammatic Representation of Categories of Energy Security Benefits**

### **ES.3 APPROACH**

In this report, methods for estimating the prospective oil security net benefits of advanced technologies being researched and developed by the DOE are proposed, implemented, and tested by estimating the prospective benefits of advanced hybrid vehicle technologies. Because the U.S. oil security problem is multi-dimensional, both monetary and non-monetary metrics of energy security are calculated. The principle monetary metric is based on comparing the combined costs of wealth transfer, economic surplus loss and macroeconomic disruption costs under “normal” (undisrupted) market conditions to those under disrupted market conditions. Benefits in scenarios that allow oil supply disruptions and consequent price shocks are compared with benefits in standard Energy Information Administration (EIA) Annual Energy Outlook (AEO) projections that do not include price shocks.

The OSM Model (OSMM) has been implemented in the form of an Excel<sup>®</sup> workbook, running under @Risk<sup>®</sup> simulation software. Use of simulation software allows uncertainty to be explicitly incorporated in the model. Three kinds of uncertainty are represented. Uncertainty about the future state of world energy markets is represented by random selection of alternative AEO projections. Uncertainty about oil supply shocks is represented by a stochastic model of oil supply shocks, calibrated to the historical record. Uncertainty about the values of critical parameters, such as the price elasticities of world oil supply and demand, is represented by specifying key parameters as probability distributions rather than point estimates.

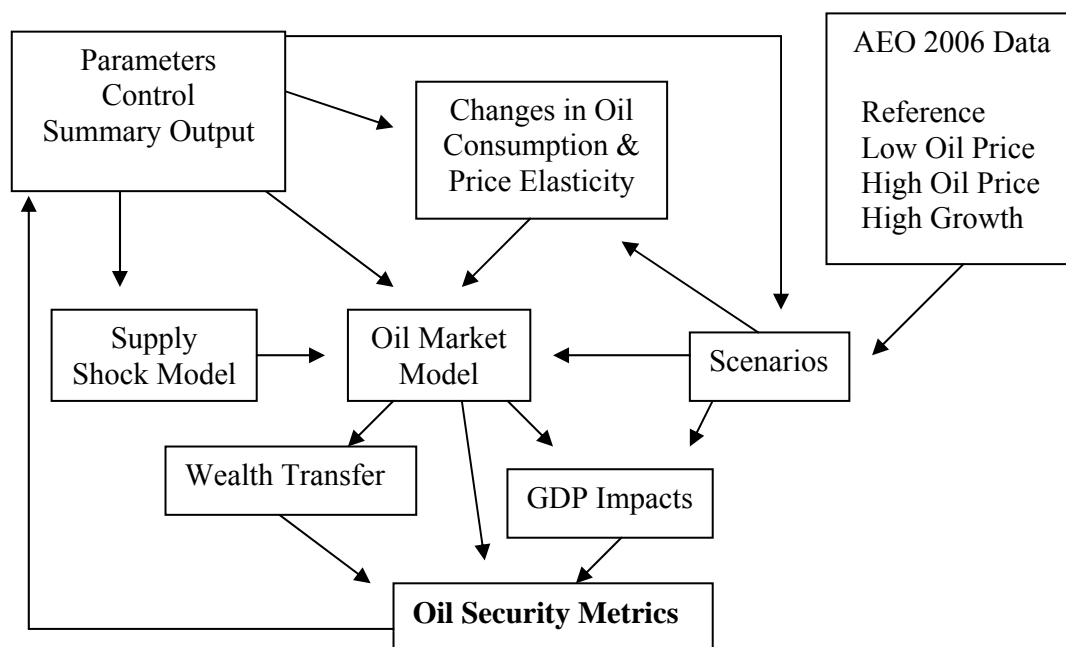
The OSMM estimates the impacts on U.S. oil security of reductions in U.S. oil demand from the AEO Reference projection, changes in the cost and performance of energy efficient technology, and changes in the costs and market shares of alternative fuels. It does not estimate the technical success of DOE R&D programs, nor their market penetration, nor their impacts on petroleum

demand. These key factors are inputs to the OSMM obtained from other DOE models and analyses.

The OSMM includes a simple, four equation model of the world oil market. Linear, lagged adjustment equations are used to represent U.S. oil demand, rest of world oil demand, U.S. oil supply and rest-of-world, non-OPEC oil supply. OPEC oil supply is exogenous. This functional form allows the model to be instantly calibrated to any AEO projection. It also allows new prices, demands and supplies to be calculated in response to oil supply shocks. Oil supply shocks are simulated by probabilistic disruptions of OPEC supply. The probability of a shock beginning in any given year, the size of a shock and its duration are random variables whose distributions have been calibrated to the historical record.

The flows among spreadsheets in the OSMM workbook are illustrated in Figure ES-2.

### Spreadsheets and Flows within Oil Security Metrics Model Workbook



**Figure ES-2. Components and Flows within the Oil Security Metrics Model**

Given a change in U.S. oil demand, OPEC is assumed to respond with one of two strategies: (1) maintain the production schedule of the original AEO projection (that does not include the change in U.S. oil demand), or (2) reduce production to restore the price of oil to the path of the original AEO projection. These two strategies are intended to bound a range of reasonable OPEC responses. In the case of a disrupted supply scenario, OPEC's strategies are to follow the disrupted production path (that does not include the change in U.S. oil demand) or to restore price to the disrupted price path (that does not include the change in U.S. oil demand).

For each simulation run, impacts of DOE's R&D programs on wealth transfer, economic surplus losses and macroeconomic disruption costs are calculated by comparing the total cost of these three components without the DOE technologies to the total costs given the impacts of the technologies on U.S. oil demand. Costs are calculated for each of the two OPEC response

strategies. Finally, oil security net benefits are estimated by subtracting the reduction in costs obtained in undisrupted world oil market simulations (without any supply or price shocks, i.e., with the oil supply disruption model turned off) from the reduction in costs obtained in disrupted market simulations.

## ES.4 METHOD

The OSMM calculates oil security net benefits by two different methods, reflecting the NRC Committee on Prospective Benefits of DOE's EERE's R&D Programs' recommendations for measuring, (1) security net benefits and (2) economic net benefits. The first method measures security benefits as the reductions in the three types of economic costs caused by oil supply disruptions: (1) transfer of wealth from the U.S. economy to oil exporting economies, (2) producers' and consumers' surplus losses as a result of the higher oil prices, and (3) macroeconomic disruption losses resulting from oil price shocks. The second method follows the Committee's recommendations for measuring economic net benefits during normal, or undisrupted market conditions, but *in future scenarios incorporating oil supply disruptions*. The difference in macroeconomic disruption costs must be added to the oil cost savings in method 2 to obtain an estimate of the total economic security benefits.

The authors recommend using the first method for its greater theoretical validity, but the Oil Security Metrics Model computes both to allow a comparison. In both cases, oil security benefits are calculated by first subtracting the sum of the three cost components given DOE's R&D programs from the sum of costs without them. The *oil security net benefits* are then obtained by subtracting the difference in costs during normal market conditions from the difference in costs realized during disrupted market conditions.

The concept of oil security involves more than price shocks, oil supply disruptions and the direct economic costs of noncompetitive pricing of oil. There are political, strategic and military consequences, as well. Reliance of the United States and its allies on Middle Eastern oil complicates U.S. foreign policy (NEPDG, 2001, p. 8-3) and creates strategic vulnerabilities to be defended. Measuring in dollars the cost of depending on unfriendly nations is intrinsically more uncertain than measuring direct economic costs. There are crucial unresolved issues with respect to definition, attribution and monetization. Many of these issues are highly politically charged. On the other hand, it would be a serious mistake to ignore such costs altogether. For this reason, the prospective oil security benefits of DOE's R&D in these areas are described by non-monetary metrics. A single exception is the SPR for which reasonable monetary and non-monetary metrics are developed.

Table ES-1 lists four non-monetary metrics recommended by Lee (2005, table 8) and fifteen related metrics that are outputs of the Oil Security Metrics Model. Of the four metrics recommended by Lee, three are directly available from the metrics model; only the price elasticity of fuel supply is currently not produced by the model.

**Table ES-1. Non-Monetary Indicators of U.S. Oil Security**

<b>Energy Security Metrics Recommended by Lee (2005)</b>	
1	U.S. Oil Imports as a percentage of consumption
2	Domestic oil consumption
3	Estimate of price elasticity of U.S. fuel supply
4	Estimate of price elasticity of U.S. oil demand
<b>Metrics Produced by the Oil Security Metrics Model</b>	
1	<b>U.S. Oil Consumption</b>
2	U.S. Oil Consumption per Dollar of GDP
3	U.S. Oil Imports
4	<b>Imports as a Share of U.S. Oil Consumption</b>
5	U.S. Wealth Transfer
6	U.S. Oil Expenditures
7	U.S. Oil Expenditures as a Share of GDP
8	SPR Size at Constant Days of Import Replacement
9	SPR Days of Import Replacement at Constant Size
10	<i>SPR Cost Savings Assuming Constant Days of Import Replacement</i>
11	<b>Estimated U.S. Price Elasticity of Oil Demand</b>
12	World Oil Price
13	OPEC Share of World Oil Market
14	OPEC Gross Revenues from Oil Sales
15	Oil Dependence Costs Relative to U.S. GDP

## ES.5 RESULTS

The OSMM was tested by estimating the oil security net benefits of advanced hybrid vehicle technology. As noted above, the OSMM does not estimate technological success, market success or the impacts of DOE's technology R&D on U.S. oil consumption. It estimates oil security net benefits as a result of given reductions in U.S. oil consumptions and changes in the cost and performance of energy efficient technologies and alternative fuels that affect the price elasticity of oil demand.

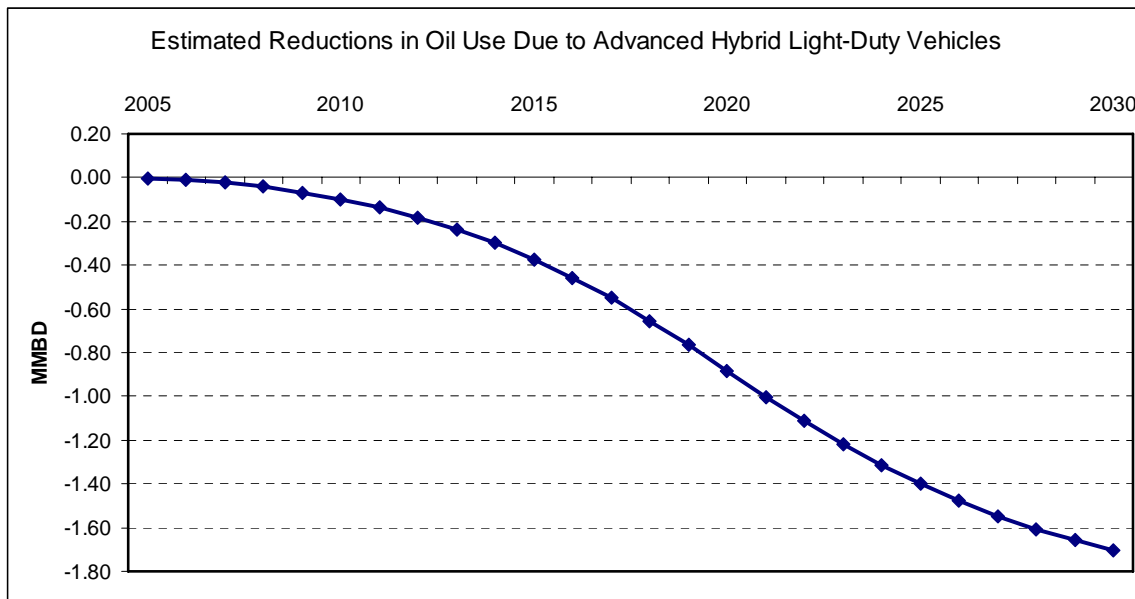
VISION Model estimates of the impacts of advanced hybrids on U.S. oil consumption were provided by Singh (2006). Estimates of the cost (retail price equivalent) and fuel economy improvement potential of advanced hybrid technology were obtained from Das (2005). Four scenarios of future oil market conditions were taken from the 2006 Annual Energy Outlook (U.S. DOE/EIA, 2006). The four AEO projections span a wide range of oil prices from \$28/bbl to \$90/bbl in 2030 (Table ES-2). OPEC production ranges from 31.7 million barrels per day (mmbd) in the High Price projection to 50.8 mmbd in the Low Price case. U.S. oil consumption is lowest in the High Price case at 25.2 mmbd in 2030 and highest in the High Growth case at 30.6 mmbd in 2030. World oil demand varies from 101.9 mmbd in the High Price case up to 127.7 mmbd in the Low Price projection.



**Table ES-2. Key Oil Market Variables from Four AEO 2006 Projections**

	2005	Reference		High Price		Low Price		High Growth	
		2015	2030	2015	2030	2015	2030	2015	2030
World Oil Price (\$/bbl)	\$49.70	\$43	\$50	\$72	\$90	\$29	\$28	\$43	\$50
OPEC Supply (mmbd)	32.15	38.3	45.8	28.9	31.7	40.6	50.8	38.3	45.8
US Demand (mmbd)	21.14	23.6	27.6	22.2	25.2	24.5	29.7	24.8	30.6
World Demand (mmbd)	87.18	96.9	117.8	90.6	101.9	101.4	127.7	96.9	117.8

The estimated reductions in light-duty vehicle energy use are shown in Figure ES-3 in millions of barrels per day. The reductions follow an s-shaped curve from no reduction in 2005 to reach -1.7 mmbd by 2030.



**Figure ES-3. VISION Model Estimates of Reductions in Oil Use as a Result of Advanced Hybrid Technology for Light-Duty Vehicles**

In relative terms, advanced hybrid vehicle technologies reduce light-duty vehicle oil use by about 0.1% in 2006, increasing to a 10% reduction by 2022 and reaching a 14% reduction by 2030. This amounts to a 6.2% reduction in total U.S. petroleum consumption by 2030 in the AEO 2006 Reference Case.

Data entry to set up a model run is accomplished in three steps. First, the estimated reductions in U.S. oil consumption are entered into the spreadsheet. The spreadsheet converts reductions measured in barrels per day to percent reductions from the AEO 2006 Reference Case to allow the reductions to be applied to the three other projection scenarios. Second, the costs and fuel economy increases for two advanced hybrid technologies are entered in the Elasticity spreadsheet. In the Elasticity spreadsheet the Excel<sup>®</sup> Solver is used to calculate the change in the price elasticity of fuel economy which, in turn is used to compute the change in the price elasticity of light-duty vehicle motor fuel demand and, finally, the change in the price elasticity of U.S. oil demand. Data entry is completed by setting key parameter values in the Parameters worksheet.

Calculating oil security net benefits requires two full simulation runs of the OSMM because the oil security net benefits are the difference between the gross benefits of DOE's R&D programs under "normal," undisrupted, market conditions and the gross benefits under disrupted market conditions. Because oil security net benefits are calculated as the difference between gross benefits in disrupted markets and gross benefits in normal or undisrupted markets the incremental costs of advanced hybrid technology cancel since the same level of market penetration is assumed in both cases. Undisrupted market conditions are simulated by turning off the stochastic supply disruption model. A set of 1,000 simulations was run without supply disruptions disturbing the AEO projections. For each individual simulation the model randomly selects one of the four AEO projections and randomly selects parameter values for those parameters that are specified as probability distributions. The @Risk simulation software keeps track of four different estimates of benefits:

1. Benefits calculated using method 1 and assuming OPEC maintains its original AEO projection oil production schedule,
2. Benefits calculated using method 1 and assuming OPEC reduces output to maintain the original AEO projection's price path,
3. Benefits calculated using method 2 and assuming OPEC maintains its original AEO projection oil production schedule,
4. Benefits calculated using method 2 and assuming OPEC reduces output to maintain the original AEO projection's price path.

A second set of 1,000 simulations was then run with the supply disruption model turned on. The same four measures of gross benefits are recorded. The expected oil security net benefits of advanced hybrid vehicle technology are the mean gross benefits obtained in the presence of supply shocks minus the mean gross benefits obtained from the simulations without price supply shocks. All benefits are discounted to present value using an annual rate of 3.0%.

The estimated mean present value gross benefits of advanced hybrid technology range from \$203 billion to \$357 billion (Table ES-3). These estimates are gross rather than net economic benefits, since no account is taken of the incremental cost of the advanced hybrid technology. In general, total benefits are greatest if OPEC does not respond to the changes in U.S. oil demand but instead maintains the original production schedule specified in the respective AEO projection. If OPEC cuts back production to maintain the AEO projection's original oil price path, the normal market gross benefits are significantly reduced.

When supply disruptions are introduced, the benefits of advanced hybrid technology increase. The increase is the net security benefit. Using the recommended method 1, the oil security net benefit varies from \$35 billion present value in the case where OPEC maintains its disrupted production schedule in the face of reduced U.S. oil demand, to \$58 billion in the case in which OPEC maintains the price of oil. Oil security net benefits are greater when OPEC attempts to maintain the original price trajectory than when it follows the original production path. This result suggests that oil security net benefits are robust with respect to strategies OPEC might adopt in response to reductions in U.S. oil demand.

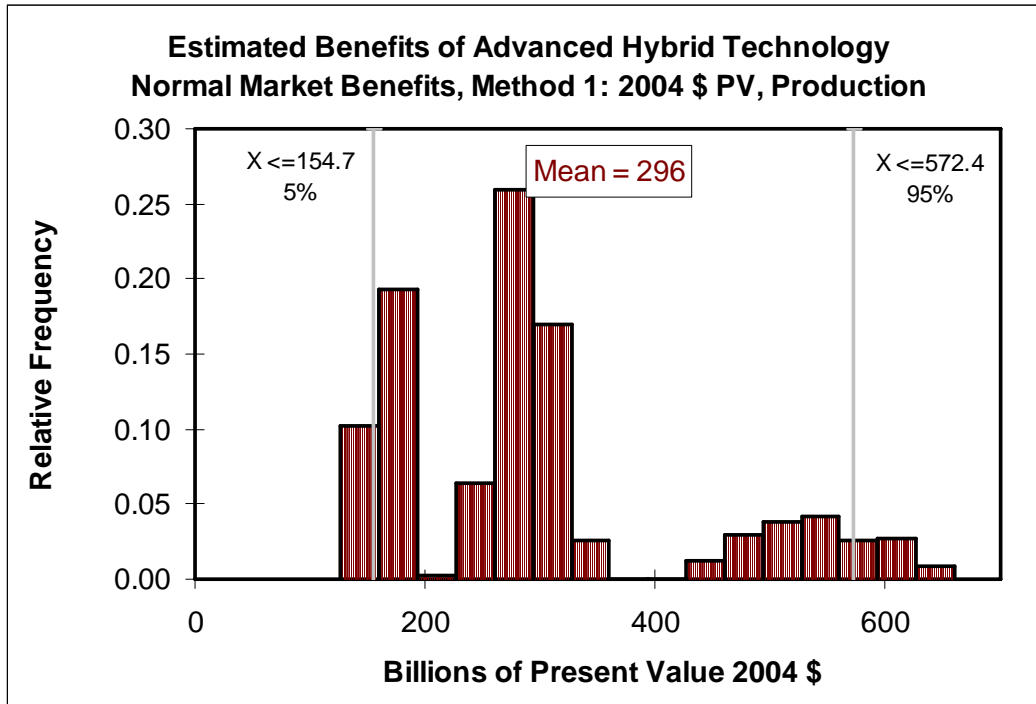
**Table ES-3. Mean Oil Security Benefits of Advanced Hybrid Vehicle Technology  
(Billions of Present Value 2004 Dollars)**

	OPEC Maintains Production	OPEC Maintains Price
	Oil Security Gross Benefits, Reference Projection Only	
Method 1	273	182
Method 2	339	224
	Oil Security Gross Benefits, No Supply Disruptions	
Method 1	296	203
Method 2	357	242
	Oil Security Gross Benefits With Supply Disruptions	
Method 1	331	261
Method 2	379	288
	Oil Security Net Benefits	
Method 1	35	58
Method 2	22	46

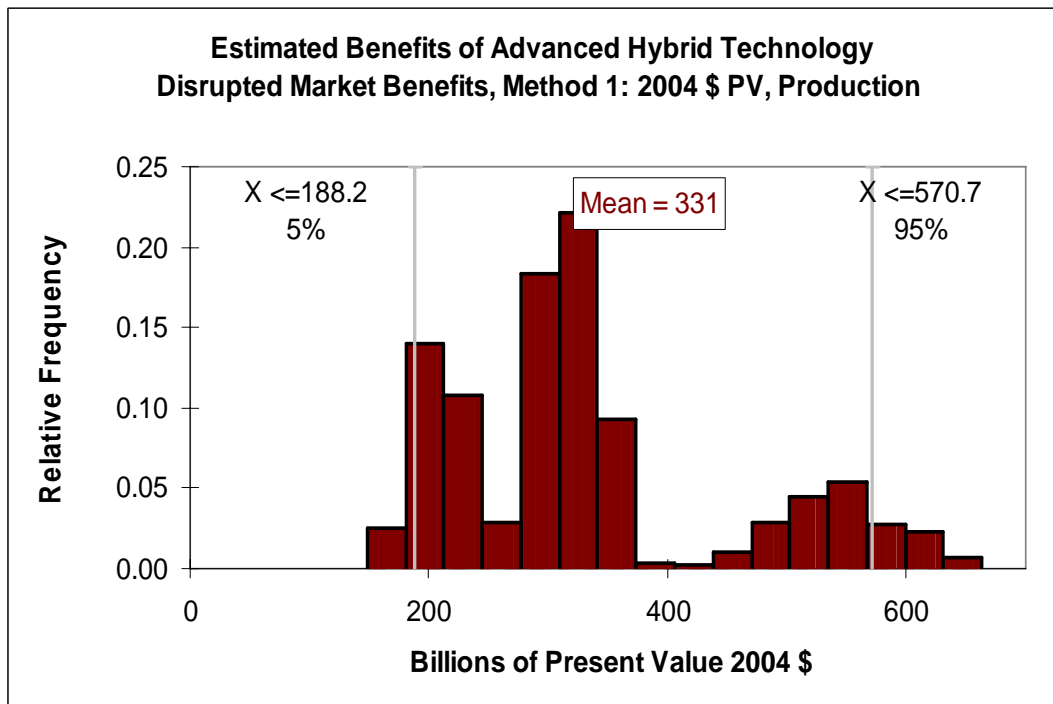
How world oil markets evolve will strongly influence the oil security gross benefits of advanced hybrid technology. Figure ES-4 displays the distribution of gross benefits from simulations with no oil supply disruptions, assuming OPEC maintains its original production schedule, and calculated using the recommended method 1. The lowest peak corresponds to the Low Oil Price projection, the highest “mound” to the High Oil Price scenario. The larger peak in the center reflects the Reference and High Growth projections, which have identical oil prices and OPEC production forecasts (Table ES-4). The expected oil security gross benefits value of \$296 billion corresponds to the “Oil Security Gross Benefits, No Supply Disruptions/Method 1” cell in Table ES-4. A 95% probability interval extends from \$155 billion to \$572 billion.

Simulations under disrupted market conditions show the same tri-modal form, but shifted upwards and compressed, with an expected value of \$331 billion and a 95% probability interval of \$188 billion to \$571 billion (Figure ES-5).

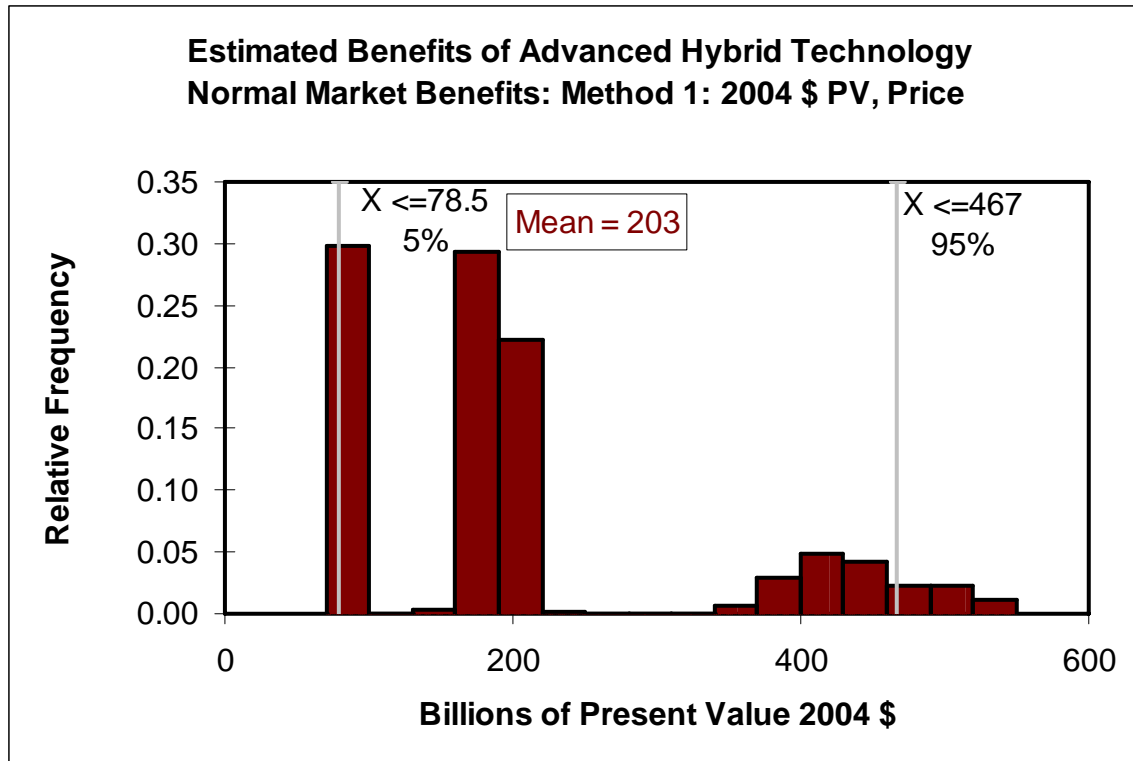
Assuming that OPEC’s response strategy is to maintain the price of oil, the expected oil security gross benefit of advanced hybrid technology is \$203 billion, present value, while the 95% probability interval is \$78.5 billion to \$467 billion (Figure ES-6). Introducing supply disruptions raises the expected gross benefit to \$261 billion and shifts the entire distribution upward. The 95% probability interval is now \$124 billion to \$492 billion (Figure ES-7).



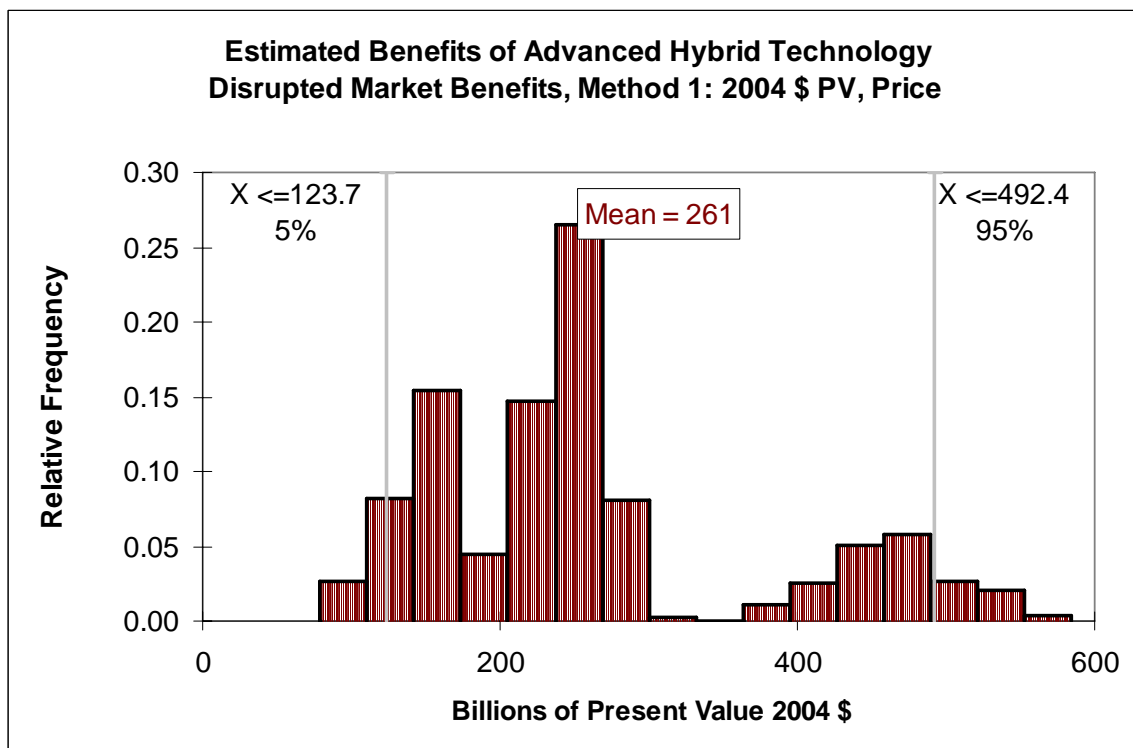
**Figure ES-4. Distribution of Estimated Normal Oil Market Benefits of Advanced Hybrid Technology for Light-Duty Vehicles**



**Figure ES-5. Distribution of Estimated Disrupted Market Benefits of Advanced Hybrid Technology for Light-Duty Vehicles**



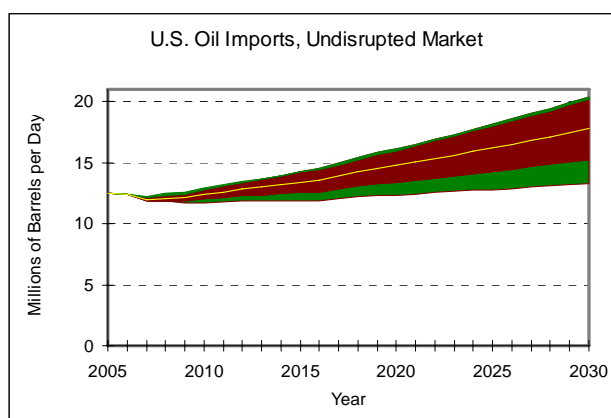
**Figure ES-6. Distribution of Estimated Normal Market Benefits of Advanced Hybrid Technology for Light-Duty Vehicles**



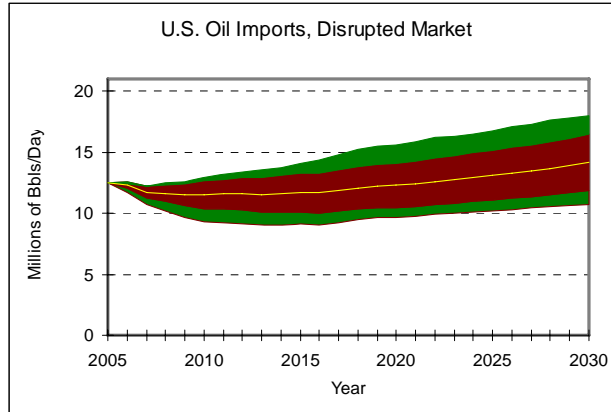
**Figure ES-7. Distribution of Estimated Disrupted Market Benefits of Advanced Hybrid Technology for Light-Duty Vehicles**

These results indicate three potentially significant conclusions. First, the oil security net benefits of advanced hybrid vehicle technology are likely to be large: on the order of \$40-\$50 billion present value. This applies to a single technology, aimed at the energy efficiency of light-duty vehicles only. Adding other vehicle types and introducing alternative fuels would greatly increase the estimates of prospective oil security net benefits. Second, the estimated oil security gross benefits of DOE's technology R&D increase substantially when uncertainty about the future is taken into consideration. Gross benefits increase when more than one scenario is used. Gross benefits increase again when price shocks are included. Benefits estimation methods that fail to reflect uncertainty about future oil market conditions will substantially underestimate the prospective benefits of DOE's R&D programs. Third, the prospective oil security net benefits of DOE's technology R&D appear to be robust to strategies OPEC might adopt to counter reductions in U.S. oil demand. In particular, if OPEC responds to reduced U.S. oil demand and increased price elasticity by cutting production to support a higher oil price, net security benefits *increase*.

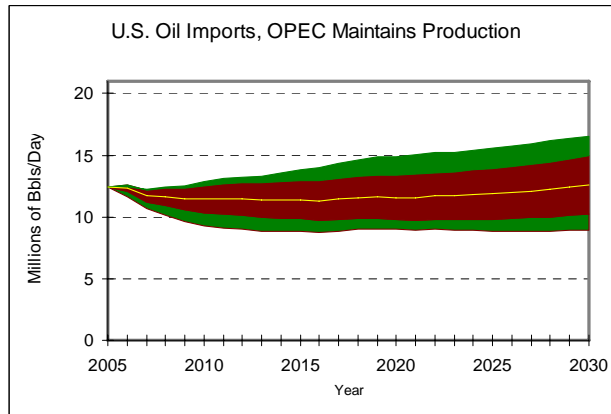
A variety of non-monetary oil security metrics are produced by the OSMM (Table ES-1). The impacts of advanced hybrid technology on just one of them, total U.S. oil imports, are illustrated in figures ES-8a to ES-8d. The first two figures illustrate oil imports in the absence of advanced hybrid vehicle technology. Figure ES-8a shows the probability distribution of U.S. imports over time assuming no supply disruptions but randomly selecting among the four AEO 2006 projections. The expected level of imports in 2030 is 17.8 million barrels per day, with an upper 5% probability limit of 20.2 mmdb. In the disrupted market scenario without advanced hybrid technology, the expected level of imports is 14.2 mmdb with an upper 5% value of 18.0 mmdb (Figure ES-8b). The lower import levels reflect the impacts of oil supply disruptions and the higher oil prices they produce. In the presence of supply disruptions, including the impact of advanced hybrid technology, and assuming OPEC maintains the same level of production as reflected in Figure ES-8b, the expected level of imports falls to 12.6 mmdb with an upper 5% value of 16.5 mmdb (Figure ES-8c). Finally, assuming OPEC maintains the oil price path rather than its production path, the expected level of imports falls by an additional 0.5 mmdb to 12.1 mmdb, with an upper 5% value of 16.1 mmdb (Figure ES-8d). Significantly, advanced hybrid technology produces significant import reductions regardless of which strategy OPEC adopts.



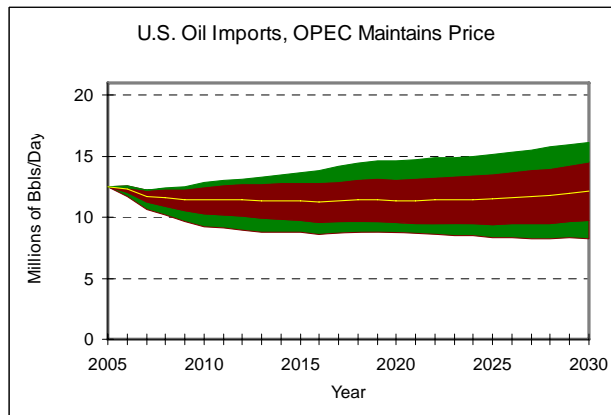
**Figure ES-8a. Summary Distribution of U.S. Oil Imports:  
Undisrupted Oil Market**



**Figure ES-8b. Summary Distribution of U.S. Oil Imports:  
Supply Disruptions**



**Figure ES-8c. Summary Distribution of U.S. Oil Imports:  
OPEC Maintains Production**



**Figure ES-8d. Summary Distribution of U.S. Oil Imports:  
OPEC Maintains Price of Oil**

The OSM Model provides a rigorous means of evaluating the prospective oil security net benefits of DOE's R&D programs. It estimates the oil market impacts of advanced technologies and alternative fuels and quantifies the prospective benefits for U.S. oil security. The OSM Model accounts for both the reduction of U.S. petroleum demand and technology-induced changes in the price elasticity of demand.

The OSM Model explicitly incorporates uncertainty about future energy markets by randomly selecting among four alternative AEO 2006 projections. Uncertainty about oil supply shocks and prices is represented by a stochastic model of oil supply disruptions. Uncertainty about key parameters, such as price elasticities, is represented by specifying them as probability distributions rather than single point estimates.

Oil security net benefits are estimated using methods consistent with the benefits estimation framework proposed by the NRC Committee on Prospective Benefits of DOE's Energy Efficiency and Fossil Energy R&D Programs (NRC, 2005) and with the energy security benefits framework developed by Lee (2005).

The proposed methods do not include estimating monetary benefits for reducing military, strategic or political costs related to oil security. Future research may be able to derive economic costs for such energy security benefits, provided that a consensus can be reached on the controversial nature of these costs. In the meantime, the proposed method does produce metrics that should be useful in qualitatively assessing the prospective benefits of EERE R&D programs from political, strategic and military perspectives.

The OSMM does not predict the technical success of DOE's R&D efforts, nor their market penetration, nor their impact on U.S. oil demand. These outcomes are estimated by other models. The OSMM is focused on estimating the oil security net benefits of such outcomes.



## 1. BACKGROUND

Energy technology R&D is a cornerstone of U.S. energy policy. Understanding the potential for energy technology R&D to solve the nation's energy problems is critical to formulating a successful R&D program. In light of this, the U.S. Congress requested the National Research Council (NRC) to undertake both retrospective and prospective assessments of the Department of Energy's (DOE's) Energy Efficiency and Fossil Energy Research programs (NRC, 2001; NRC, 2005)<sup>2</sup>. The NRC Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy completed its retrospective assessment in 2001 and concluded that in aggregate the benefits of DOE's R&D efforts exceeded their costs (NRC, 2001). However, in its report on Phase 1 of its prospective study, the Committee expressed some dissatisfaction with the state of the art of prospective benefits evaluation, noting, "...that the methodologies by which DOE calculated the benefits of its programs had varied considerably, thus making comparisons of program benefits difficult." (NRC, 2005, p. ES-2).

In 2004, the NRC Committee on Prospective Benefits of DOE's Energy Efficiency and Fossil Energy R&D Programs published a report recommending a new framework and principles for prospective benefits assessment. The Committee explicitly deferred the issue of estimating security benefits to future work. Recognizing the need for a rigorous framework for assessing the energy security benefits of its R&D programs, the EERE developed a framework and approach for defining energy security metrics for R&D programs to use in gauging the energy security benefits of their programs (Lee, 2005). Lee's metrics framework covers not only oil security, but electric power reliability and the security of critical energy infrastructure.

This report describes methods for estimating the prospective oil security benefits of EERE's R&D programs that are consistent with the methodologies of the NRC (2005) Committee and that build on Lee's (2005) framework. Its objective is to define and implement a method that makes use of the NRC's typology of prospective benefits and methodological framework, satisfies the NRC's criteria for prospective benefits evaluation, and permits measurement of the most significant prospective energy security benefits of EERE's R&D portfolio.

The method proposed has been implemented using spreadsheet software augmented by risk analysis capabilities. It requires as inputs U.S. DOE Energy Information Administration (EIA) Annual Energy Outlook forecasts of future U.S. and world oil market conditions to 2030, as well as estimates of the timing and technological success of DOE/EERE's R&D programs and their impacts on U.S. petroleum use. It produces a comprehensive evaluation of prospective oil security benefits during disrupted and undisrupted market conditions, as well as metrics for political, strategic and military benefits. Uncertainty is explicitly included in the evaluation by means of Monte Carlo simulations and the use of alternative energy market forecasts.

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<sup>2</sup> "The Congress continued to express its interest in R&D benefits assessment by providing funds for the NRC to build on the retrospective methodology to develop a methodology for assessing prospective benefits." (NRC, 2005, p. ES-2)



## 2. PROSPECTIVE BENEFITS AND THE NRC “BENEFITS MATRIX”

The challenge of evaluating the benefits of DOE’s R&D programs was well described by the NRC Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy (NRC, 2001). The Committee’s charge was to estimate retrospective benefits and costs, but the same issues, plus additional uncertainty, arise in the evaluation of prospective benefits.

“In theory, evaluating the benefits and costs of DOE’s research program should be relatively straightforward. It would require adding up the total benefits and costs of research conducted since 1978, determining what proportion of each is attributable to DOE funding, and calculating the difference between the DOE contributions and the cost of achieving them. In practice, methodological challenges abound. Of these, the most fundamental is how to define and systematically capture the diverse benefits that result from publicly funded research within a dynamic environment of marketplace activity, technological advancement, and societal change.” (NRC 2001, p. 2)

As the NRC (2001) Committee points out, the first challenge is defining the benefits that should be measured. The Committee noted that the justification for public research rests on the existence of public benefits that the private sector cannot capture. This does not imply that only the public goods benefits of DOE programs should be counted, but rather that the public goods benefits must be large enough to justify a public investment in R&D that would not be justified on the basis of private benefits alone. In other words, if public plus private benefits exceed total costs but private benefits alone do not, then public investment in R&D may be justified. Both the public and private benefits of the R&D should be and are counted in the benefits defined by the NRC Committee.

The NRC Committee on Prospective Benefits recommended that the prospective benefits of DOE’s R&D programs be summarized in a “results matrix” (Figure 1). The results matrix defines the fundamental dimensions of prospective benefits analysis. The matrix divides the benefits of DOE programs into three categories:

- “*Economic net benefits* are based on changes in the total market value of goods and services that can be produced in the U.S. economy under normal conditions, where “normal” refers to conditions absent energy disruptions or other energy shocks and the changes are made possible by technological advances stemming from R&D.
- *Environmental net benefits* are based on changes in the quality of the environment that have occurred or may occur as a result of a new technology RD&D program.
- *Security net benefits* are based on changes in the probability or severity of abnormal energy-related events that would adversely impact the overall economy, public health and safety, or the environment.” (NRC, 2001, pp. 2-3)

All three categories of benefits are important. However, only security benefits are addressed in this report.

While capturing the majority of the potential economic and security benefits of DOE’s R&D programs, these definitions appear to exclude two important categories of potential benefits. The

first is the transfer of wealth from the U.S. economy that occurs as a result of monopoly pricing of oil or in the form of windfall profits in the event of a supply disruption not caused by noncompetitive behavior. The second is the reduction of costs of insuring against the risk of abnormal energy-related events that create volatile oil prices.

If the economic benefits definition applies only to the value of goods and services produced (i.e., Gross Domestic Product [GDP]), it excludes the transfer of wealth from U.S. consumers to foreign oil producers as a result of the exercise of market power or the windfall profits from a supply disruption (see, e.g., Huntington and Eschbach, 1987). Huntington (2005) has termed this effect an “OPEC tax,” while recognizing that OPEC may not always be the initiator of the price increase.

“Oil price increases, however, have another effect that is excluded by conventional GDP measures. A permanent oil price increase will reduce the country’s income and purchasing power, requiring the nation to export more goods and services to import each barrel of oil. Even if oil price increases do not influence output (GDP), they will reduce real domestic income.” (Huntington, 2005, p. 4.)

		Global Scenario		
		Reference Case	High Oil and Gas Prices	Carbon Constrained
Program Risks	Technical Risk			
	Market Risks			
Expected Program Benefits	Economic Benefits			
	Environmental Benefits			
	Security Benefits			

**Figure 1. NRC (2005) “Benefits Matrix”**

When oil prices rise, wealth is transferred outside the U.S. economy to oil exporting countries and also within the U.S. economy from oil consumers to oil producers. The transfer within the U.S. economy is not counted as wealth transfer cost since it remains within the U.S. economy. The transfer of wealth has been shown to be a major component of the costs of oil dependence, accounting for approximately one-third of the total direct economic costs (Greene and Ahmad, 2005). Although wealth transfer occurs in “normal” market conditions, it is magnified in the event of a supply disruption that causes an oil price shock.

The definition of energy security benefits, on the other hand, appears to include only disrupted market conditions. If so, it would miss energy security costs that may be ongoing under “normal” market conditions. Such costs are a consequence of actions taken by the United States to protect or insure itself against possible supply disruptions and price shocks. These actions include measures ranging from acquiring and maintaining strategic stockpiles (e.g., the Strategic Petroleum Reserve [SPR]) to enhancing military preparedness to deal with contingencies that might disrupt the flow of oil from critical oil exporting regions. Clearly, reductions in the costs of insuring the nation against the damaging effects of possible supply disruptions are as much a public good benefit as a reduction in the impacts of disruptions.

The NRC (2005) report notes that their Benefits Matrix appropriately focuses on “...the public good benefits – economic, environmental and security – that are the objectives of DOE’s applied energy R&D programs. Public good benefits can be produced in a variety of ways. At least three are relevant to evaluating the prospective benefits of DOE’s R&D programs.

1. Provision or enhancement of pure public goods, e.g., national security;
2. Mitigation of public good externalities, e.g., improved environmental quality;
3. Mitigation of other kinds of market failures, especially imperfect competition.

For example, a reduction in the market power of the Organization of Petroleum Exporting Countries (OPEC) cartel would also be a public good in the third category.<sup>3</sup> All oil consumers benefit when OPEC’s market power is reduced and one consumer’s benefit does not diminish another’s. The benefits of reducing OPEC’s market power necessarily flow to all who consume oil products or goods whose production requires oil. Since virtually the entire transportation system is dependent on petroleum, this includes everyone.

A key feature of the NRC (2005) framework is the explicit recognition of uncertainty. The NRC (2005) study identified three kinds of uncertainties:

1. Uncertainty about the technological outcome of a program.
2. Uncertainty about the market acceptance of a technology.
3. Uncertainty about future states of the world.

Since this report does not address predicting the technological outcomes of DOE programs or their market success, it will focus on uncertainty about future states of the world. In the benefits matrix, uncertainty about future states of the world is represented by three alternative scenarios in the context of which benefits are to be assessed. Two are standard forecasts produced annually by the Energy Information Administration (EIA) for its Annual Energy Outlook. A third case represents the likelihood that carbon emissions from energy use will have to be significantly reduced.

1. Reference Case
2. High Oil Price Case
3. Carbon Constrained

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<sup>3</sup> Public goods are distinguished from private goods by two attributes. Public goods are nonexcludable and nonrivalrous (Kahn, 1995). A good is nonrivalrous when its consumption by one individual does not diminish the amount of the good available for another. A good is nonexcludable when if one person can consume a good, others cannot be excluded from consuming it. Diminishing the market power of the OPEC cartel satisfies both criteria.

None of the three scenarios reflect the disrupted market conditions that are the prerequisite for oil security net benefits. Methods have been developed for quantifying the probability distributions of the occurrence, size, and duration of oil market disruptions (e.g., Beccue and Huntington, 2005; Leiby and Bowman, 2000; Huntington et al., 1997). These methods allow the uncertainties inherent in oil market disruptions to be explicitly represented via simulation modeling. In this report it is proposed that oil security net benefits be estimated by comparing the distributions of economic costs from multiple simulation runs under disrupted market conditions with the costs incurred in the undisrupted EIA projections.

## 2.1 DEFINITIONS

The central question for developing oil security metrics is defining the phenomena to be measured. This analysis begins with the definitions proposed by the National Research Council's Committee on Benefits of DOE R&D on Energy Efficiency and Renewable Energy (NRC, 2001). The Committee divided all benefits into three categories: (1) economic, (2) environmental, and (3) security. The Committee's definitions of economic and security benefits are the following (emphasis added).

**“Economic net benefits** are based on changes in the total market value of goods and services that can be produced in the U.S. economy under normal conditions, where ‘normal’ refers to conditions absent energy disruptions or other energy shocks.” (NRC, 2001, p. 15)

**“Security net benefits** are based on changes in the probability or severity of abnormal energy-related events that would adversely impact the overall economy, public health and safety, or the environment. Historically, these benefits arose in terms of national security issues, i.e., they were benefits that assured energy resources required for a military operation or a war effort. Subsequently, they focused on dependence upon imported oil and the vulnerability to interdiction of supply or cartel pricing as a political weapon. More recently, the economic disruptions of rapid international price fluctuations from any cause have been emphasized.” (NRC, 2001, p. 15)

The Committee emphasized that benefits should be estimated net of all public and private costs. In this report benefits and net benefits will be used to describe benefits net of all costs; gross benefits will refer to benefits from which all public and private costs have not been subtracted.

This report deals only with oil security net benefits. Security benefits associated with other primary and final energy forms are not considered in this report (see, e.g., Lee, 2005 for a comprehensive review of energy security benefits). Not only does this exclude issues related to the electricity grid, for example, but questions of refinery and petroleum product infrastructure security, as well.

Like the most recent NRC (2005) report, the Oil Security Metrics Model is concerned with potential future, or prospective, rather than past or retrospective benefits. Because the future is uncertain, and particularly so with respect to “abnormal” market conditions, the OSM simulates a large number of possible future oil market scenarios. The result is a distribution of prospective

oil security net benefits. It is often convenient to describe the results in terms of expected, or mean, net benefits.

Finally, the categories for which quantitative measures, or metrics, are developed can be divided into those that can be readily measured in constant, present value dollars and those for which monetary metrics are either not appropriate or highly controversial. The benefits that can be measured monetarily are comprised of, (1) transfer of wealth, (2) economic surplus losses, and (3) macroeconomic disruption costs. Each of these components is defined in detail below. Non-monetary costs include the political, strategic and military risks associated with oil insecurity.

The categories of benefits discussed above and those that are covered in this report are illustrated in Figure 2.

ENERGY SECURITY GROSS BENEFITS		
ENERGY SECURITY NET BENEFITS		PUBLIC AND PRIVATE COSTS
NON-OIL SECURITY NET BENEFITS		
OIL SECURITY NET BENEFITS		DIFFERENCE BETWEEN OIL SECURITY GROSS AND NET BENEFITS
MONETARY METRICS (PV, 2004 \$)	NON-MONETARY METRICS	
1. Transfer of Wealth 2. Economic Surplus Losses 3. Macroeconomic Disruption Costs	Political Risk Strategic Risk Military Costs	

**Figure 2. Diagrammatic Representation of Categories of Energy Security Benefits**





### 3. A FRAMEWORK FOR PROSPECTIVE OIL SECURITY BENEFITS

In this section, the energy security metrics framework proposed by Lee (2005), which forms the basis of the oil security metrics used in this study, is briefly reviewed. In the following section, Lee's non-monetary metrics are shown to be the key determinants of the direct economic costs of oil insecurity.

Methods for measuring energy security benefits were not addressed in Phase 1 of the NRC (2005) report, but were intentionally left for consideration in Phase 2 of the study. Focusing exclusively on energy security benefits, Lee (2005) has recommended a general framework for their assessment. According to Lee (2005), DOE programs may produce energy supply security benefits in four ways:

1. reduce the probability of a supply disruption,
2. reduce the loss of capacity in the event of a disruption, which has two dimensions,
  - a. the magnitude of the disruption
  - b. the duration of the disruption
3. reduce the net supply shortage resulting from the loss of capacity, and
4. reduce the adverse impact of the shortage and resulting economic damage.

Like the NRC study, Lee (2005) excludes political, strategic and military costs associated with energy security and the costs of actions taken to insure against the adverse impacts of possible disruptions. While such benefits are controversial and difficult to quantify, assigning them a value of zero clearly biases benefits estimates downward. In the absence of rigorous methods for assigning monetary values to these benefits, non-monetary metrics are proposed as indicators of potential progress in addressing these costs.

Lee's framework was intended to be applicable to all kinds of energy security events from electricity blackouts to oil market disruptions. With respect to oil market disruptions, which occur in a global market for a fungible commodity, the distinction between supply disruption and net supply shortage is less useful. Indeed, if markets are allowed to function a supply disruption will result in no net energy shortage because prices will rise to equilibrate supply and demand. Thus, the following modification to Lee's framework is adopted.

1. reduce the probability of an oil supply disruption,
2. reduce the decrease in supply as a result of the disruption,
3. reduce the price increase as a result of the disruption,
4. reduce the other adverse consequences and damages from the disruption, and
5. reduce the cost of actions necessary to protect or insure against disruptions (e.g., SPR) at a given level of protection.

Initially, it is not proposed that the benefits estimation methodology attempt to predict the impacts of EERE's R&D programs on the probability of an oil supply disruption. There appear to be no rigorous methods for making such a prediction at the present time. Although there is no accepted method for predicting the likelihood of oil price shocks, useful research has been done

on indicators.<sup>4</sup> However, with additional research and analysis, it should be possible to quantify these relationships in a convincing way.

Energy security metrics proposed by Lee are shown in Table 1. Four specific metrics are proposed for oil security, none of which is measured in dollars.

1. Domestic oil consumption
2. Oil imports, total and as a percentage of consumption
3. Price elasticity of fuel supply
4. Price elasticity of U.S. oil demand

These metrics are indeed the most significant factors affecting U.S. oil security that can be directly influenced by EERE's R&D programs. But, as is argued below, these metrics can be used to calculate prospective oil security net benefits measured in dollars. Translating Lee's metrics into dollar estimates begins with analyzing the oil security problem, followed by formulating a rigorous, yet transparent, modeling framework for calculating benefits. Still, not all important prospective benefits can be as readily measured in dollars. For these, non-monetary metrics are proposed.

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<sup>4</sup> For example, an indicator of the likelihood of a price shock based on the rates of growth of supply and demand was developed by Santini (1999). Certainly, in theory, there should be a connection between such factors as the rate of growth of oil consumption, the level of world oil demand, the price elasticities of oil supply and demand (especially in the short run), the market share of the OPEC cartel, etc., and the probability of an oil price shock.

**Table 1. Preliminary Suggestions for Energy Security Metrics from Lee (2005, table 8)**

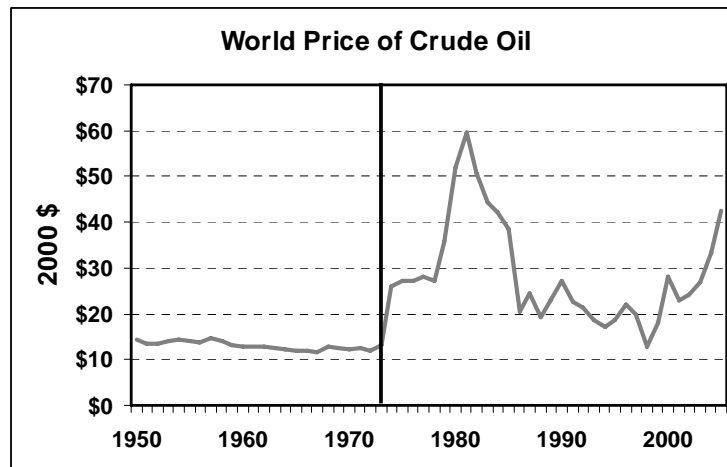
Type of Energy Security Concern	R&D Programs in EERE That Improve Energy Security	Energy-Security Impact of Technologies Developed in R&D Programs	Impacted Factors Affecting Energy Security	Suggested Energy-Security Metrics
Security of Energy Supply	Biomass FreedomCAR/Vehicle Hydrogen, Fuel Cells Industrial Technologies	Reduced oil imports	<ul style="list-style-type: none"> <li>• Reduced probability of threat of disruption</li> <li>• Reduced cost of maintaining threat at acceptable level</li> <li>• Reduced impact and damage, in the event of disruption</li> </ul>	Oil imports as a percentage of consumption
	FreedomCar/Vehicle Hydrogen, Fuel Cells Industrial Technologies	Reduced demand for petroleum products	<ul style="list-style-type: none"> <li>• Reduced probability of threat of disruption</li> <li>• Reduced cost of maintaining threat at acceptable level</li> <li>• Reduced impact and damage, in the event of disruption</li> </ul>	Domestic oil consumption
	Biomass FreedomCar/Vehicle Geothermal Hydrogen, Fuel Cells Solar Wind and Hydropower	Increased price elasticity of supply	<ul style="list-style-type: none"> <li>• Reduced loss in production capacity, in the event of disruption</li> <li>• Reduced cost of maintaining capacity, in the event of disruption</li> <li>• Reduced net loss in production, in the event of disruption</li> <li>• Reduced cost of maintaining net change in production, in the event of disruptions</li> </ul>	Estimate of price elasticity of fuel supply
	Biomass Federal Energy Manage. FreedomCar/Vehicle Geothermal Hydrogen, Fuel Cells Solar Weatherization, Intergov. Wind and Hydropower	Increased price elasticity of demand for fuels	<ul style="list-style-type: none"> <li>• Reduced impact and damage, in the event of disruption</li> </ul>	Estimate of price elasticity of U.S. oil demand



#### 4. OIL SECURITY AND ENERGY TECHNOLOGY R&D

The root of the United States' oil security problem is economic and strategic dependence on an energy commodity, (1) whose resources are concentrated in an unstable region, (2) whose supply is vulnerable to disruption by various causes and subject to substantial collusive control by a cartel of oil producing nations, and (3) for which demand and supply are highly inelastic, especially in the short-run. Petroleum is the single largest source of energy for the U.S. economy and its use is highly concentrated in the transportation sector, a sector vital to all economic activity and one that to this day has found no ready substitute for petroleum fuels. The combination of these factors has created a situation in which supply disruptions, whether intentional or unintentional, can produce very large and sudden price increases that do significant damage to the U.S. economy. To the extent that DOE's R&D programs can reduce the level of U.S. petroleum demand or increase its price elasticity by advances in the technologies that use oil or produce substitutes for oil, they can deliver oil security benefits to the U.S. economy.

The U.S. and world oil security problem became evident in 1973 when Arab members of OPEC first exercised market power by imposing an oil boycott on the United States in retaliation for its support of Israel in the October War (Yergin, 1992, Ch. 29). Over the previous decade the nations of OPEC had consolidated their control of the oil resources in their countries and formed a cartel of sovereign states holding about three quarters of the world's proven oil reserves. The world oil market changed profoundly in 1973 and has not been the same since (Figure 3). Over the next three decades OPEC proved to be far from a perfectly operating cartel, always functioning with limits on its market power and coping with the differing agendas of its members. Nonetheless, OPEC has demonstrated on several occasions its ability to raise and sustain high prices by restricting oil supply, thereby generating vast monopoly profits (e.g., Kohl, 2002; Smith, 2005). The cumulative costs to the U.S. economy of the OPEC-dominated oil market regime have been counted in trillions of dollars (Greene and Ahmad, 2005).<sup>5</sup>



**Figure 3. World Oil Prices, 1950-2005 (EIA, Ann. Energy Rev., tables 5.18 & 5.21)**

<sup>5</sup> The chief difficulty and source of disagreement in retrospectively estimating the costs of U.S. oil dependence is what to compare history to. Greene and Leiby (1993), Greene and Tishchishnya (2001) and Greene and Ahmad (2005) compare history to hypothetical competitive market conditions. Some other analysts appear to accept the existence of market power as unchangeable and compare history to a market without price shocks but with higher than competitive market prices.

Over the past three decades there have been several different kinds of oil supply disruptions. There have been supply reductions deliberately initiated by OPEC members for political reasons (as in 1973-73) and for economic reasons (as in 1999-2000). There have been disruptions initiated by armed conflicts and sustained by deliberate OPEC action (as in the case of the Iran-Iraq War and the supply restraint lasting from 1979 to 1985). But supply shocks have also been cut short by OPEC nations expanding production (e.g., the Persian Gulf War in 1990-1991). And temporary supply disruptions have been caused by hurricanes, accidents and other factors. Oil security is affected by all such supply shocks, whether they are the result of non-competitive pricing of oil or other market instabilities.<sup>6</sup>

The complexity of this experience has led to considerable debate about the degree to which OPEC exerts monopoly power in world oil markets. In light of this, it seems reasonable to recognize two kinds of market failures causing oil security costs:

1. imperfect competition due to the use of monopoly power by members of OPEC, and
2. the inability of private actors to capture the public good benefits of protecting the economy against the damage of oil price shocks.

The fact that market power is a key part of the energy security problem implies that reducing or eliminating the market power of the oil cartel should be a cornerstone of energy policy. Because it is not feasible to “bust” the cartel the way government regulators would break up a monopoly within the U.S. economy, technological change is very likely the best strategy for solving the oil security problem (e.g., Parry and Anderson, 2005, p. 15). Taxing oil to “internalize” externalities would not *solve* this aspect of the oil security problem, though it would almost certainly be helpful.

In a static oil market, the market power of the oil cartel rests on three key factors:

1. its market share,
2. inelasticity of world oil demand, and
3. inelasticity rest-of-world oil supply.

The inelasticity of world oil supply and demand, especially in the short run, is also responsible for the extreme sensitivity of world oil markets to supply disruptions. The relationship between the three factors is captured in a simple theoretical formula, derived in 1952 by von Stackelberg, for the profit-maximizing price for a monopolist who controls part, but not all, of a market.<sup>7</sup>

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<sup>6</sup> “Since the 1970s, the crude oil market has, at times, been heavily influenced by the OPEC cartel. Because the member countries control a large share of world production and total reserves, these countries have been able to influence crude oil prices by limiting supply through the use of country-by-country production quotas. These quotas have, at times, served to maintain a tight balance between world supply and world demand. However, because of the relative political instability in the Middle East and some of the other OPEC countries (such as Nigeria and Venezuela), occasional oil supply disruptions and prices shocks have been a fact of life for about the past 30 years and may remain an issue for the foreseeable future.” (Wells, 2005, p. 10)

<sup>7</sup> As shown in the appendix to this report, the cartel’s market power also depends on the rate of growth of world oil demand and the rate of change in supply.

$$P = \frac{C}{\left(1 + \left[\frac{1}{\beta} s(\eta + 1)\right]\right)} \quad (1)$$

$P$  is the price that maximizes the cartel's profits,  $C$  is the cost of producing oil,  $\beta$  is the price elasticity of world oil demand,  $s$  the cartel's market share, and  $\eta$  is the response of rest of world (ROW) oil suppliers to a reduction in OPEC supply, at constant price. The denominator must be between 0 and 1 and, thus, the term in square brackets must be less than 0 but greater than -1; the closer the term in square brackets is to -1, the larger the profit maximizing price. It is clear from von Stackelberg's (1952) equation that the smaller the price elasticity of demand, the larger the cartel's market share, and the smaller the ROW supply response, the greater the cartel's market power (i.e., the higher the price that maximizes the cartel's profits). This formula is also an index of market power because the higher the profit maximizing price relative to production costs, the more the monopolist can increase its revenues by decreasing production.<sup>8</sup> Growing world oil demand magnifies the cartel's market power, as would declining rest-of-world supply.

A key fact not evident in equation (1) is that short-run (approximately one-year) elasticities of supply and demand are roughly an order of magnitude smaller than long-run (ten- to fifteen-year) elasticities. As a result, the profit-maximizing price for the cartel in the short-run is far higher than the profit-maximizing price it can sustain indefinitely. The same phenomenon explains why relatively small oil supply disruptions can lead to large but usually temporary oil price spikes. Holding other factors in equation (1) constant, the profit-maximizing cartel price can be plotted as a function of the cartel's market share (Figure 4). Bounds are placed around the short-run (upper) and long-run profit-maximizing price curves to indicate uncertainty about many key parameters. Nonetheless, a plot of world oil prices and cartel market shares from 1965 to 2005 reveals that almost all post-1973 activity falls between the curves and that, in general, achieving or maintaining very high prices requires the cartel to continually cut back on production, sacrificing market share.

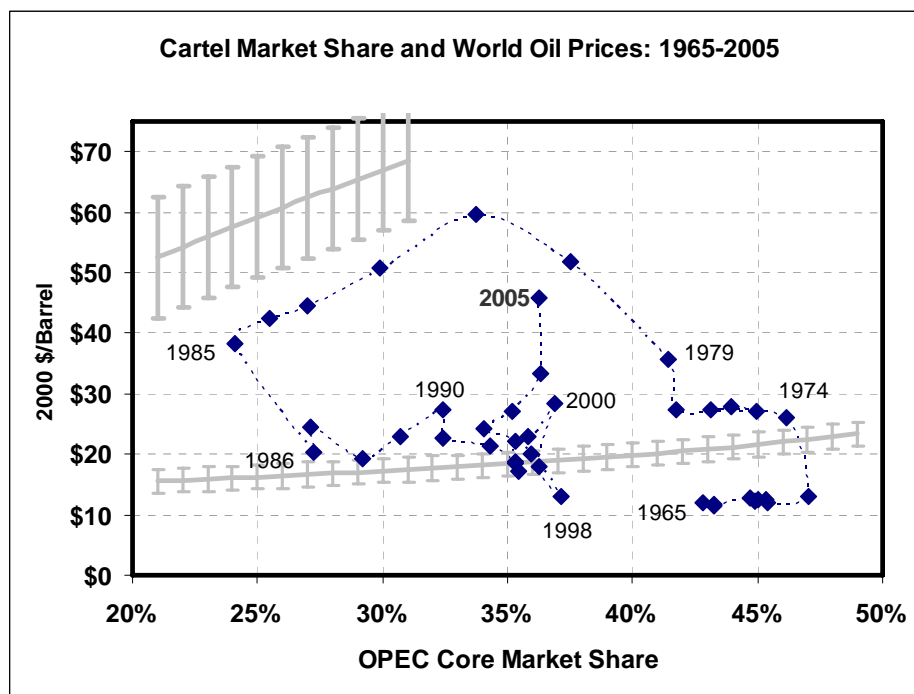
The United States consumes more petroleum than any other nation, alone accounting for 25% of world petroleum use. Because of this, a decrease in U.S. petroleum use will cause the world price of oil to fall or, if OPEC decides to defend the price of oil in the face of reduced U.S. demand, it will reduce the cartel's share of the world oil market. A decrease in petroleum use per dollar of GDP would also diminish the harm oil supply disruptions could do to the U.S. economy.

Increasing the price elasticity of demand could also be a powerful strategy for reducing the cartel's market power and moving closer to a competitive oil market. Greater price responsiveness would also help to mitigate the price increase from a supply shock regardless of its cause. Two factors determine the price elasticity of demand: (1) consumers' preferences, and (2) the technical ability to substitute energy efficiency or alternative energy sources for oil. Achieving the goals of DOE's energy R&D would make it possible to do more with less oil and

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<sup>8</sup> As Greene (1991) pointed out, the fact that short-run price elasticities of supply and demand are approximately and order of magnitude smaller than long-run price elasticities creates the potential for instability in a cartelized market. Wirl (1990) and Suranovic (1993; 1994) showed how this in this situation a series of price shocks could be more profitable for a monopolist than stable prices.

make it easier and cheaper to substitute other forms of energy for oil. Both changes will generate energy security benefits.



**Figure 4. World Oil Prices and OPEC Market Shares, 1965-2005**



## 5. THE COSTS OF OIL INSECURITY

Oil security benefits can be measured by two different methods, reflecting the NRC Committee on Prospective Benefits of DOE's Energy Efficiency and Renewable Energy R&D Programs' recommendations for measuring, (1) security net benefits and (2) economic net benefits. The first method measures security benefits as the reductions in the three types of economic costs caused by oil supply disruptions: (1) transfer of wealth from the U.S. economy to oil exporting economies, (2) producers' and consumers' surplus losses as a result of the higher oil prices, and (3) macroeconomic disruption costs resulting from oil price shocks. The second method follows the Committee's recommendations for measuring economic net benefits during normal, or undisrupted market conditions, but *in future scenarios incorporating oil supply disruptions*. This method measures benefits as reductions in the total economic costs of oil as a result of the impacts of DOE's R&D, minus the costs of implementing the technological changes. The difference in macroeconomic disruption costs must be added to the oil cost savings to obtain an estimate of the total economic security benefits.

The authors recommend using the first method for its greater theoretical validity, but the Oil Security Metrics Model computes both to allow a comparison. In both cases, oil security gross benefits are calculated by subtracting total costs given DOE's R&D programs from the total costs without them. The *oil security net benefits* are obtained by subtracting the benefits of DOE's R&D programs during normal market conditions from the benefits realized during disrupted market conditions.

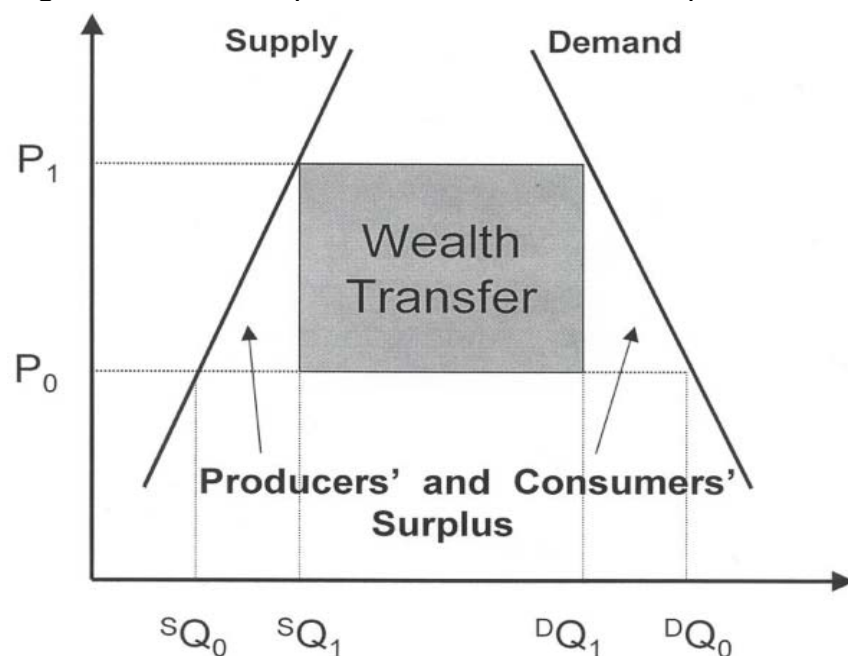
Following the guidance of the NRC, normal conditions are defined those that are "...absent energy disruptions or other energy shocks..." (NRC, 2001, p. 2) Undisrupted conditions are represented by various Energy Information Administration Annual Energy Outlook Projection Cases. The AEO Cases typically reflect different states of the world but do not include supply disruptions and price shocks and, with the exception of certain advanced technology cases, do not include the impacts of DOE's R&D programs. Technological advances allow more to be produced with less oil, and can also increase the economy's ability to respond to price shocks. In futures in which supply disruptions and price shocks occur, the same programs can have greater benefits.

The NRC Committee defined security net benefits as reductions in costs due to "...changes in the probability or severity of abnormal energy-related events that would adversely impact the overall economy, public health and safety, or the environment." (NRC, 2005, p. 16) There appears to be no definitive method available at the present time with which to quantitatively estimate how DOE's R&D would change the probability of oil supply disruptions. Thus, the method proposed here relies on benefits resulting from changes in the severity of disruptions and the severity of their economic impacts. Two categories of impacts are measured: (1) oil security net benefits, measured in discounted present value dollars, and (2) non-monetary security benefits which are indicated by a variety of metrics. Future costs are discounted to present value at a rate of 3%/year, as recommended by the NRC Committee (NRC, 2005, p. 17).

## 5.1 OIL SECURITY NET BENEFITS

Oil Security Net Benefits are calculated as a reduction, as a consequence of the DOE's technology R&D, of damage done to the U.S. economy *in future scenarios incorporating oil supply disruptions*. These costs are comprised of three, mutually exclusive components: (1) transfer of wealth from U.S. oil consumers to foreign oil producers, (2) loss of consumers' and producers' surplus due to the greater economic scarcity of oil, and (3) disruption losses due to economic dislocations caused by oil price shocks. Once again, oil security net benefits are calculated by subtracting the benefits of DOE's R&D in undisrupted scenarios from the benefits in disrupted scenarios.

The transfer of wealth is distinct from GDP losses.<sup>9</sup> Their relationship illustrated in Figure 5. The U.S. economy imports oil because at market prices its domestic supply curve does not intersect its demand curve. At the hypothetical competitive market price,  $P_0$ , the quantity of U.S. imports equals  $^DQ_0 - ^SQ_0$ . At the higher disrupted price  $P_1$ , the U.S. imports  $^DQ_1 - ^SQ_1$ . The triangles under the supply and demand curves (labeled producers' and consumers' surplus) are deadweight economic losses and will reduce potential GDP. The rectangular area is the transfer of wealth to foreign oil producers and will not necessarily reduce U.S. GDP (Huntington, 2005; Huntington and Eschbach, 1987) depending on how the resulting changes in foreign trade affect the final demand for U.S. output. Nonetheless, wealth transfer is a real economic loss from the perspective of the U.S. economy. The transfer of wealth is exactly equal to the quantity of actual oil imports at the higher price,  $P_1$ , multiplied by the difference between the actual price of oil and what the price would have been in a competitive (or undisrupted) market. Unless oil imports are small relative to total consumption, it is clear that the transfer of wealth will be large relative to direct producers' and consumers' surplus losses.



**Figure 5. Relationship of Wealth Transfer to Deadweight Economic Losses and to Oil Imports**

<sup>9</sup> This analysis of transfer of wealth costs due to supply disruptions and price shocks applies equally to the analysis of costs due to non-competitive oil supply. Monopoly pricing of oil, even in undisrupted market creates wealth transfer and potential GDP losses for the U.S. economy.

Both surplus losses and the transfer of wealth can occur during “normal” as well as “disrupted” market conditions if market power is used to raise oil prices above a competitive market level. Price *shocks*, however, create a third type of economic loss. Sudden oil price changes cause economic dislocations that result in temporary underemployment and misallocation of resources, and thereby a temporary excess loss of GDP beyond what the higher price level alone would induce. Leiby and Bowman (2000) identify three principal transmission mechanisms by which oil price shocks reduce GDP: (1) sectoral shocks, (2) investment uncertainty, and (3) demand composition. Sectoral shocks work via firms’ demands for inputs to production. The sudden change in the price of oil changes the optimal mix and characteristics of labor, capital and other inputs. The resulting adjustments, including job destruction and job creation, temporarily reduce output below what will ultimately be achievable. Investment uncertainty causes firms to delay planned capital outlays and purchases while they discern new strategies for the new market conditions. Price shocks can also suddenly change consumers’ demand for goods and services. Adjustment of output to the new pattern of demand takes time. Once again, the resulting process of job destruction and creation produces a temporary period of increased unemployment and lost productivity. Recent research has illuminated the mechanisms by which oil price shocks cause GDP losses and confirmed that the price shocks themselves rather than monetary policies adopted in response to the shocks are the primary cause of economic losses (Jones, Leiby and Paik, 2004).

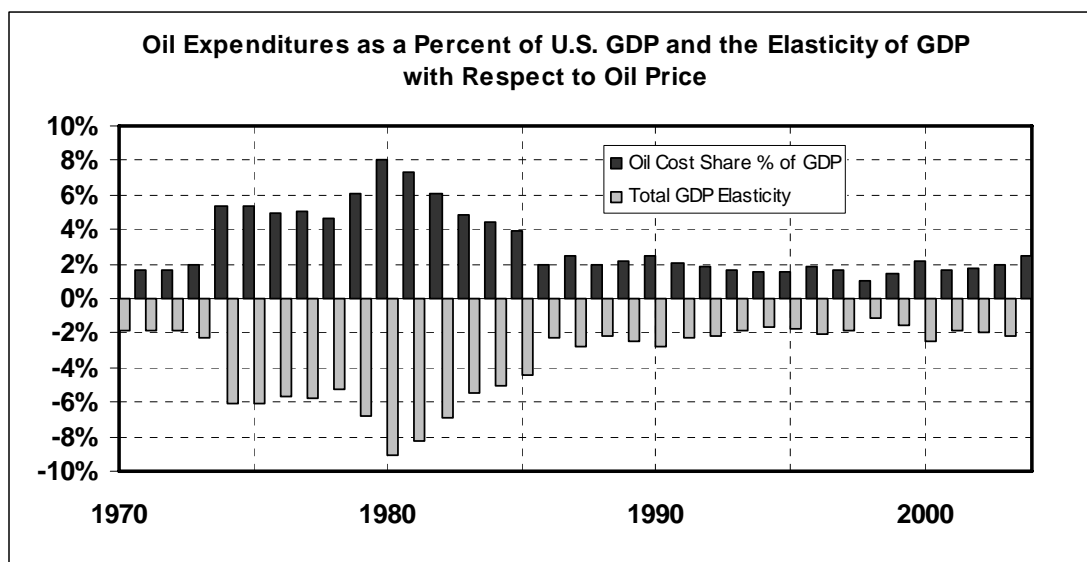
Most studies summarize the impact of oil price shocks on GDP in the form of an oil price elasticity of GDP. Estimates vary, but according to a recent survey (Jones, Leiby and Paik, 2004), -0.055 appears to be a reasonable central estimate, implying that a 50% increase in the price of oil would reduce GDP by about 2.7%. Another recent survey (Huntington, 2005) settled on -0.048 as a reasonable central estimate. These elasticity estimates represent the combined impacts of the macroeconomic disruption effects and the consumers’ and producers’ surplus losses that make up the loss of potential GDP. In an upward price shock, the two effects work in concert to reduce GDP. But when oil prices suddenly fall, the dislocation effect tends to reduce GDP while consumers’ and producers’ surplus gains tend to increase GDP. The resulting asymmetric response of GDP to upward and downward oil price shocks has led empirical researchers to formulate a variety of price shock variables (e.g., see Huntington, 2005 or Jones, Leiby and Paik, 2004 for reviews). Here the two effects, dislocation and surplus, are estimated separately. The sum of the two effects will inherently respond asymmetrically to upward and downward price shocks.

Greene and Ahmad (2005) and Huntington (2005), among others, argue that the oil price elasticity of GDP should be expected to vary in proportion to expenditures on petroleum in relation to GDP. Huntington (2005) offers the following equation, in which the oil price elasticity of GDP varies according to the oil value share of GDP:

$$\frac{dY/Y}{dP/P} = b \left( \frac{Q}{Y} \right) \quad (3)$$

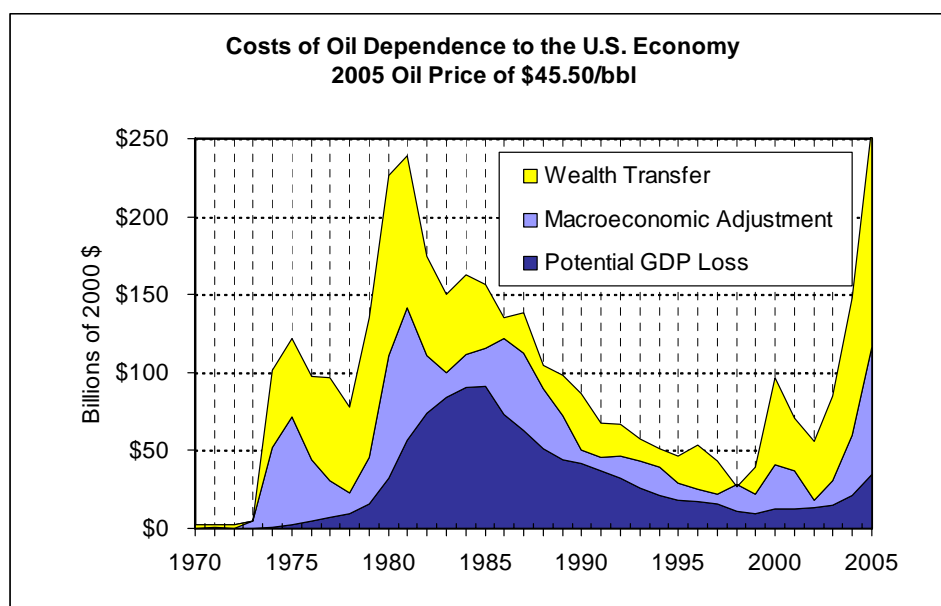
where P, Q, and Y refer to the price of oil, the quantity of oil consumed and real GDP, respectively. The hypothesized relationship is illustrated in Figure 6, in which the elasticity in 1983 is assumed to be -0.055. Whether oil shock impacts are constant or a function of the oil

intensity of the economy is important to assessing the oil security benefits of DOE R&D programs, since a primary goal of the programs is to reduce petroleum consumption.



**Figure 6. Expenditures on Petroleum as a Percent of U.S. GDP**

The retrospective costs of U.S. oil dependence from all three sources were estimated by Greene and Ahmad (2005). Their analysis suggests that the direct economic costs have been large, and that the three components are comparable in magnitude (Figure 7). Greene and Ahmad created a spreadsheet-based computer model to estimate the three types of costs, and used Monte Carlo simulation methods to incorporate uncertainty in their methodology. The same kind of approach is adapted here to prospectively estimate the benefits of changes in U.S. oil dependence that may be achieved by DOE's R&D programs. Greene, Jones and Leiby (1998) also used similar methods to prospectively estimate the effects of increased price elasticities of oil supply and demand on the costs to the U.S. economy of a hypothetical future supply shock.



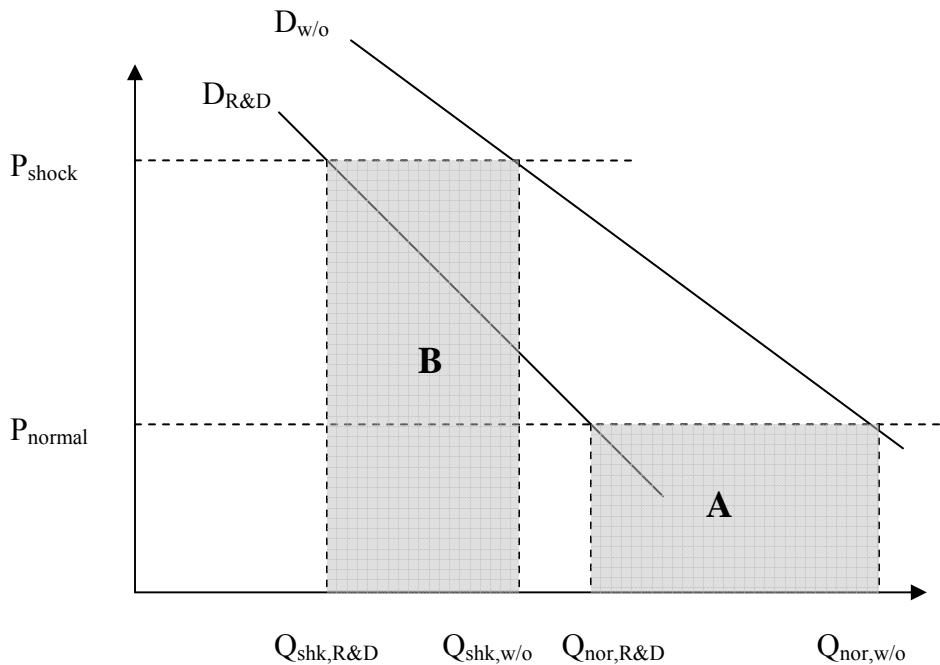
**Figure 7. Retrospective Estimates of the Costs of Oil Dependence (Greene & Ahmad, 2005)**

## 5.2 ECONOMIC NET BENEFITS

The second method is based on the simple premise that the economic net benefits of technology may be greater in periods of oil market disruptions than in undisrupted periods. Economic net benefits of technologies that improve the efficiency of oil use or substitute other energy sources for oil can be estimated by subtracting the costs of implementing the technologies from the total value of oil saved. This follows the NRC Committee's recommended approach for estimating economic net benefits from the reduced economic costs of energy services (NRC, 2001, p. 89). A second key premise is that the costs of implementing technology are the same in undisrupted and disrupted scenarios. Given these two premises economic oil security benefits can be obtained by subtracting the reduction in oil expenditures due to DOE's R&D in normal periods from the savings in periods in which there are supply disruptions.

Figure 8 graphically illustrates the calculations of economic net benefits under the assumption that the world price of oil is not affected by the implementation of DOE R&D technologies. In the absence of DOE programs and in normal market conditions, expenditures on oil are  $P_{\text{normal}}Q_{\text{nor,w/o}}$ . With the implementation of advanced technology, the oil demand curve shifts from  $D_{\text{w/o}}$  to  $D_{\text{R\&D}}$ , and expenditures decrease to  $P_{\text{normal}}Q_{\text{nor,R\&D}}$ , for a savings of A. The net economic benefits are equal to A minus the cost of implementation.

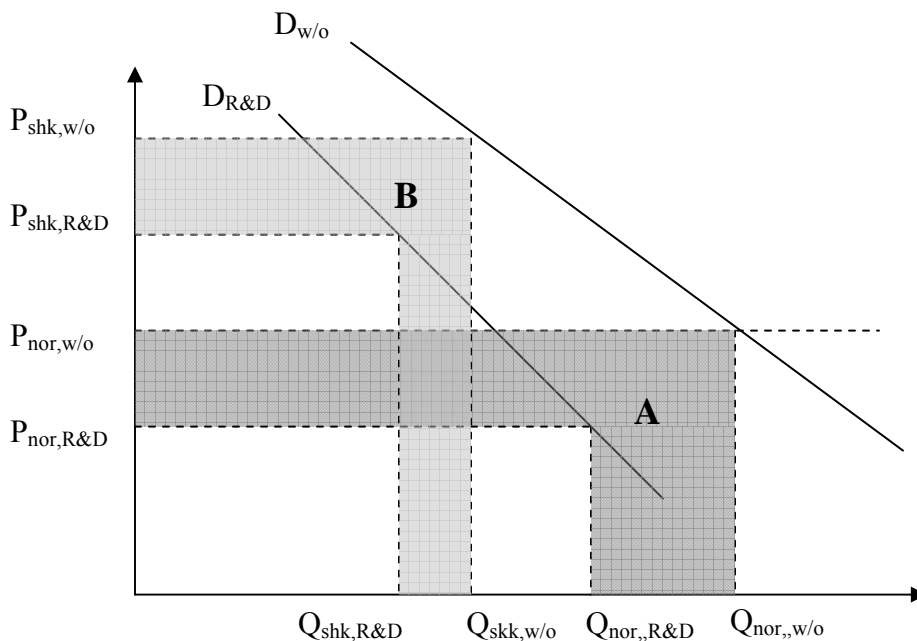
$$\text{Benefits} = (\text{Oil Exp}_{\text{w/o}} - \text{Oil Exp}_{\text{R\&D}} - \text{Cost})_{\text{disrupted}} - (\text{Oil Exp}_{\text{w/o}} - \text{Oil Exp}_{\text{R\&D}} - \text{Cost})_{\text{undisrupted}} \quad (2)$$



**Figure 8. Gross Oil Savings Benefits Given No Change in World Oil Price**

However, world oil prices may fall in response to a reduction in U.S. oil demand. Figure 9 illustrates savings on oil expenditures in that case. In normal market conditions savings are the difference between the rectangle  $P_{\text{nor,w/o}}Q_{\text{nor,w/o}}$  and  $P_{\text{nor,R\&D}}Q_{\text{nor,R\&D}}$ . In disrupted conditions, the savings are,  $P_{\text{shk,w/o}}Q_{\text{shk,w/o}} - P_{\text{shk,R\&D}}Q_{\text{shk,R\&D}}$ . Assuming the implementation costs are the same

whether there are supply shocks or not, the security net benefits are the difference between the two shaded areas, or **B-A**.



**Figure 9. Gross Oil Savings Benefits Given a Reduction in World Oil Price**

### 5.3 NON-MONETARY OIL SECURITY METRICS

The concept of oil security involves more than price shocks, oil supply disruptions and the costs of noncompetitive pricing of oil. There are political, strategic and military consequences, as well. Reliance of the United States and its allies on Middle Eastern oil complicates U.S. foreign policy (NEPDG, 2001, p. 8-3) and creates strategic vulnerabilities to be defended.

“On our present course, America 20 years from now will import nearly two of every three barrels of oil – a condition of increased dependency on foreign powers that do not always have America’s interests at heart.” (NEPDG, 2001, p. x)

Measuring in dollars the cost of depending on unfriendly nations is intrinsically more uncertain than measuring direct economic costs. There are crucial unresolved issues with respect to definition, attribution and monetization. Many of these issues are highly politically charged. On the other hand, it would be a serious mistake to ignore such costs altogether. For this reason, the prospective benefits of DOE’s R&D in these areas will be described by non-monetary metrics. A single exception is the SPR for which both a monetary and non-monetary metrics can be developed.

#### 5.3.1 Military Costs

Despite the inherent difficulties, several analysts have attempted to quantify the military and strategic costs of oil dependence (e.g., Copulos, 2003; Moore, Behrens and Blodgett, 1997; Delucchi and Murphy, 1996; Hall, 1990). These studies illustrate the fact that U.S. military

expenditures associated with the oil producing regions of the world are so large that almost any conceivable attribution to oil security would lead to the conclusion that the military costs are of the same order of magnitude as the gross oil security costs discussed above. Hu (1997) surveyed assessments of military expenditures on defending oil supplies for the year 1996 and came up with a range of estimates from \$6 billion to \$60 billion dollars. The GAO (1991) estimated that from 1980 to 1990, approximately \$33 billion per year was spent defending Middle East oil supplies. Delucchi and Murphy (1996) derived an estimate of \$20 billion to \$40 billion per year (1992 \$) for defending all U.S. interests in the Persian Gulf, and asserted that between 25% and 50% of these costs are not related to oil (leaving \$10B to \$30B oil related). More recently, Copulos (2003) arrived at an approximate, best estimate of \$44 billion and an alternative conservative estimate of \$37 billion for defending Persian Gulf oil in the year 2003. His report also contains an extensive discussion of the difficulties and uncertainties involved in deriving such an estimate.

Not all analysts agree with this reasoning, however. Counter arguments assert that the United States non-oil interests in the region, together with the dependence of other countries on oil from the Persian Gulf, are sufficient to justify the existing military expenditure levels.

"Third, it is misleading to attribute the costly U.S. presence in the Middle East solely to the nation's high degree of oil dependence and to argue that import reductions could significantly reduce the costs of Middle East involvement. As noted, materially reducing U.S. oil imports would be extremely costly—and the rest of the industrialized world would remain highly dependent on uncertain Middle East oil supplies. Moreover, the U.S. presence in the Middle East serves ends beyond oil security. Reducing U.S. oil imports would do little to lessen this presence." (Toman, 2002)

A similar assertion was made in a study by the Congressional Research Service (Moore, Behrens and Blodgett, 1997).

"In terms of military expenditures related to the Middle East, even if oil imports from the region could be minimized, U.S. geopolitical interests there relate to far more than oil."

It is important to note that both observations apply to reducing U.S. oil imports or reducing oil imports from the Middle East, rather than reducing U.S. oil consumption as well as oil imports. Neither asserts that if the U.S. oil consumption were zero, military expenditures associated with the Middle East region would be unaffected. Also, neither asserts that there are no military costs associated with U.S. oil dependence; rather they argue that they may not be as large as others have estimated.

Estimates of the military costs of U.S. oil dependence are subject to the following objections:

1. Attribution of any military costs to defending U.S. oil security is indeterminate because military units can and do serve multiple purposes.
2. The relationship between oil consumption and military preparedness and military actions is not direct, but depends on a number of other factors and is likely to be subject to threshold effects (i.e., reducing U.S. oil consumption by 1 mmbd might

- have no effect on military costs but a reduction of 10 mmbd could have a large impact).
3. The United States' energy security is not only influenced by U.S. oil dependence but by the dependence on oil of our allies and trading partners (NEPDG, 2001, pp. 1-13, 8-1 to 8-3).

These are all valid observations and yet, even taken together they do not imply that there are not military costs of oil dependence nor that these costs are unrelated to factors that could be changed by technologies that are the subject of DOE's R&D. None of the critics of military cost estimates argue that technological changes that drastically reduced or eliminated U.S. oil imports or oil consumption would have no strategic or military benefits.

The literature cited above suggests the following as meaningful non-monetary metrics of strategic and military oil security costs:

1. Total U.S. oil consumption
2. U.S. oil imports
3. Middle East or OPEC share of the world oil market.

The first two indicate the vulnerability of the United States, the latter the vulnerability of the rest of the world.

### **5.3.2 Oil Revenues and the Transfer of Wealth**

Another potential oil security problem stems from the enormous surplus wealth oil provides to oil exporting states. This in-flow of surplus wealth to oil producers is the other side of the wealth transfer coin. *The Economist* magazine has referred to this as the "oil curse."

"Oddly enough, the biggest losers from the rise in oil nationalism may be the citizens of countries blessed with hydrocarbons....On the whole, though, the oil bounty tends to get misspent, and the poorest citizens of the countries concerned rarely see the benefits, a phenomenon known as the oil curse." (Economist, 2005)

Some have drawn a connection between the surplus oil wealth of the Gulf States and terrorism.

"Yet the wealth and increasing reach of many groups and individuals with extremist views, in conjunction with the absence of democratic institutions in the Gulf, create conditions for the further radicalization of the region. However, as one observer noted, it is not political oppression and poverty that have produced terrorists in the Gulf States, but wealth, privilege, and education." P. 26 (Johnston, Runci and Riggs, 2002).

Others point to oil profits as a key source of funding for terrorists and their activities.

"In addition, sending less money to Saudi Arabia would mean less money in the hands of a regime that has spent the past few decades doling out huge amounts of its oil revenue to mosques, madrassas and other institutions that have fanned the fires of Islamic radicalism. The oil money has been dispensed not just by the



Saudi royal family but by private individuals who benefited from the oil boom – like Osama bin Laden, whose ample funds, probably eroded now, came from his father, a construction magnate. Without its oil windfall, Saudi Arabia would have had a hard time financing radical Islamists across the globe.” (Maass, 2005).

Others point to the oil wealth as one cause of the loss of influence of western states in the Middle East.

“Several European governments have been urgently negotiating with Iran to dissuade it from pursuing nuclear weapons. One of the most attractive incentives they could offer has been investment capital. But Iran suddenly needs it much less: since early 2005, Iran’s oil export earnings are now projected to run about \$15 billion a year higher than the year before.” (Parry and Anderson, 2005, p. 15)

A blunt assessment of the link between oil dependence and national security was made by Parry and Anderson (2005, p. 15).

“Throughout the Middle East, this wave of unexpected new revenue has flooded into countries not all of which are well equipped to keep it from reaching violent political factions and terrorists. The routes and magnitudes are unknown. But it is evident that the insurgency against the U.S. presence in Iraq is not suffering from inadequate financial support.

“To the extent that Americans have contributed to the rise in oil prices through their steadily rising demand for oil, they appear to have undercut their own foreign policy goals and their own national security interests.” (Parry and Anderson, 2005, p. 15)

This view has been echoed in the popular media, as well.

“Over the last three decades, Islamic extremism and violence have been funded from two countries, Saudi Arabia and Iran, not coincidentally the world’s first and second largest oil exporters. Both countries are now awash in money and, no matter what the controls, some of this cash is surely getting to unsavory groups and individuals.” (Zakaria, *Newsweek*, 2005).

“We know wealthy Saudis are funding terror. With higher oil prices, they just have more money to do so.” (Attributed to R. Bronson, Council on Foreign Relations: Lynch, 2005.)

Not all agree that increased wealth in oil exporting countries leads to instability. Some have argued the reverse is the case.

“... one of the main causes of instability in the region is declining oil revenues. Saudis who've gotten used to living on the state's generous oil dole, for example, are now finding that the dole has been cut by 70 percent since 1980 and that jobs are scarce. Because there's no other source of revenue for these economies other

than oil, a major production cutback would bankrupt the OPEC countries and almost certainly trigger revolutions." (Taylor and VanDoren, 2001)

At the very least, since military expenditures must necessarily come from social surplus, the monopoly rents from oil exports present an opportunity to spend vast sums on military equipment and armed forces and even to fund terrorist operations. Because oil production costs for OPEC members, especially in the Middle East, are very low relative to oil prices, total OPEC revenues is a reasonable metric of the flow of surplus wealth to Middle East oil producing states.

### **5.3.3 The Cost of Insuring Against Supply Disruptions**

Actions taken to insure the nation against the adverse impacts of possible future oil supply disruptions also have a cost. Following the oil price shock of 1973-74, the International Energy Agency was created by OECD countries, in part to coordinate the development and use of Strategic Petroleum Reserves (SPRs). The IEA's Director recently reaffirmed the commitment of oil consuming nations to protect the public welfare from the continuing risk of oil supply disruptions.

"These are indeed grave events and grave threats. But the geopolitical risk to continuity of oil supply is, in itself, nothing new. These are but current, concrete examples of the known geopolitical risk, against which the governments of the industrialized world decided, over twenty five years ago, they must protect their citizens." (Priddle, 2002).

Appropriate metrics reflecting the prospective impact of EERE programs on the costs of SPRs can be inferred from studies carried out to determine the optimal size of the SPR. Leiby and Bowman (2000) assert that the optimal size of strategic reserves should depend on the probability and magnitude of supply shocks, their impact on oil price, and the vulnerability of the economy to oil price shocks. In particular, they note that "shock import costs" (referred to here as transfer of wealth) are the product of the quantity of oil imported and the change in price. They also point out that the change in price is a function of the world short-run price elasticity of oil demand.

Leiby and Bowman (2000) estimated the costs of expanding the U.S. SPR at approximately \$0.4B (96\$) per 100 million barrels. Estimates such as this could be used to quantify avoided costs if the size of the SPR could be predicted as a function of objective oil market conditions. Leiby and Bowman's (2000) methods for estimating the optimal size of the SPR could clearly be adapted to calculate optimal SPR size in any AEO scenario, disrupted or undisrupted. Until these methods can be adapted to this purpose, the following non-monetary metrics can be used to approximate the impacts of DOE R&D programs on SPR costs.

1. Days of import replacement afforded by an SPR of fixed size (e.g., 675 million barrels).
2. Size of an SPR capable of providing a fixed number of days of import replacement (e.g., 57 days).

The second non-monetary metric implies a related monetary metric, i.e. the difference in the costs of SPRs capable of supplying a fixed number of days of imports in the base case versus the cases affected by EERE technologies. The relevant costs are comprised of the following:

1. capital and operating cost savings due to a smaller SPR,
2. oil purchase cost savings, and
3. opportunity costs savings due to holding less oil in the SPR.

This metric would underestimate the benefits of reducing oil imports if the value of increased SPR protection (increased days of import replacement) exceeded the cost of maintaining or increasing the size of the SPR.



## 6. METHODS FOR ESTIMATING PROSPECTIVE BENEFITS

In this section methods for estimating the prospective oil security net benefits of DOE's R&D programs and for producing useful non-monetary metrics of national security benefits are described. The methods intended to be consistent with the NRC (2005) committee's proposed objectives for a methodology for estimating the prospective benefits of energy R&D.

1. Rigorous in its calculation of benefits and assessment of risks.
2. Practical and consistent process for applying across DOE programs.
3. Transparent and easy to use.
4. Not require extensive resources.
5. Not difficult for stakeholders to understand.

Adequately assessing the prospective benefits of DOE's R&D programs requires recognizing that their chief goal is to transform technology. Technological advances reduce the quantity of petroleum used for a given level of economic output and also increase opportunities for substitution away from oil. DOE's transportation sector R&D programs to improve oil security are focused on three key areas:

1. energy efficient technology,
2. production of alternative and renewable energy, and
3. utilization of alternative and renewable energy.

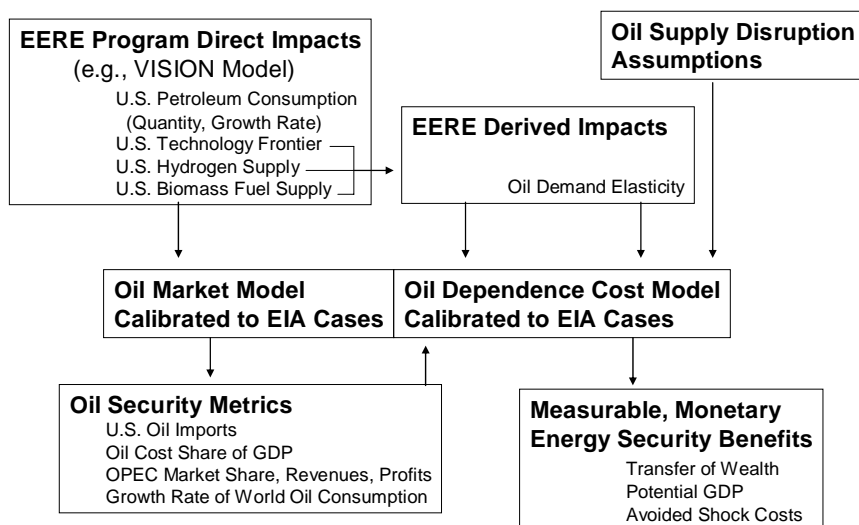
In every case, the intent of the R&D is to expand the technology frontier, i.e. to allow greater efficiency to be achieved or more non-petroleum fuel to be produced or utilized at lower cost. Prospective benefits assessment must explicitly account for the impacts of technological change not only on the quantity of petroleum used but on the economics of substituting other energy sources for petroleum.

The methods proposed in this report have been implemented in the Oil Security Metrics spreadsheet model that can be calibrated to any AEO oil market projection. The model therefore is able to assess impacts in alternative futures, represented by alternative AEO projections. Use of spreadsheet software insures the transferability of the model. Commercially available simulation software is used to allow uncertainties to be incorporated in varied and flexible ways. Simulation methods combining risk analysis and scenario analysis allow the inclusion of uncertainty about key parameter values, future states of the world and even the relationships between variables, i.e., uncertainty about how the world works (Lempert, Popper and Bankes, 2003). The process for estimating prospective oil security net benefits is illustrated in Figure 10.

Alternative states of the world oil market are represented by alternative AEO projections, to which a dynamic, linear simultaneous equation model of the world oil market is calibrated. The simple, four-equation oil market model is self-calibrating so that alternative AEO scenarios can be randomly chosen in the course of a simulation run. Potential oil supply disruptions are characterized by probability distributions representing their likelihood, duration and magnitude, and are introduced via Monte Carlo simulation. Expenditures on oil, wealth transfer costs, potential GDP losses and macroeconomic disruptions costs, with and without DOE R&D impacts are calculated for each simulation run using the methods described below. Oil security

net benefits are the difference in economic costs between disrupted and undisrupted simulations. Non-monetary metrics are also computed for each simulation run, producing a distribution of time paths for each indicator that can be summarized graphically or by measures of central tendency and variability.

### Estimation of prospective oil security benefits of EERE's programs using performance metrics.

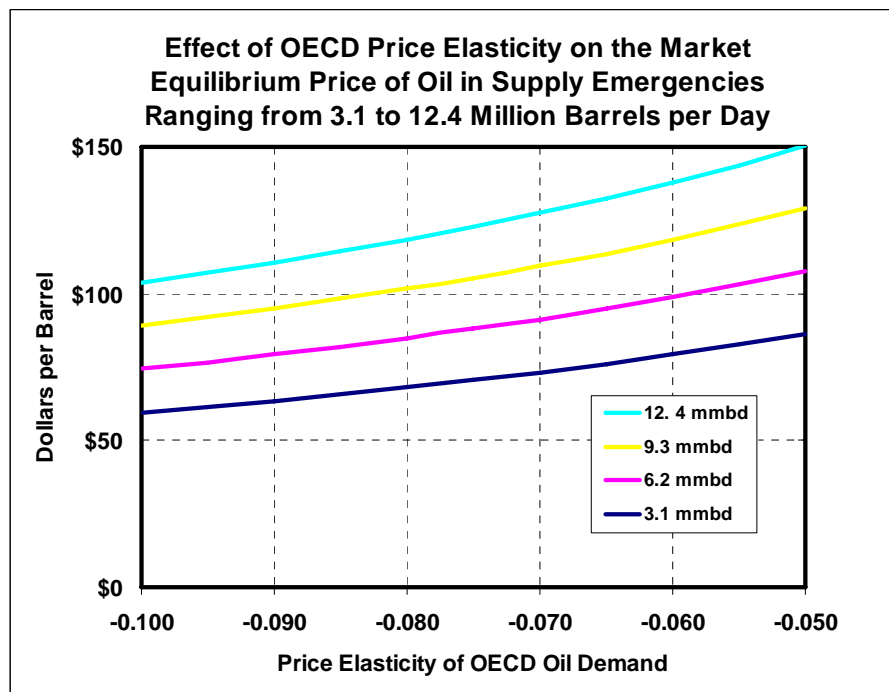


**Figure 10. Schematic Representation of Methodology for Estimating Prospective Oil Security Benefits of EERE's R&D Programs**

DOE's program impacts are estimated by translating the program goals into two key measures: (1) the reduction in U.S. petroleum use over time, and (2) the change in the price elasticity of U.S. oil demand over time. Both energy efficiency and fuel substitution effects must be included. DOE EERE has developed models for estimating the potential market success of its programs and calculating the impacts on petroleum consumption. The VISION model, for example, has been extensively used to estimate reductions in petroleum use over time as a consequence of improvements in vehicle efficiency and the market penetration of alternative fuels (Singh, Vyas and Steiner, 2003). The VISION model can be calibrated to alternative Annual Energy Outlook cases, and then re-run using the estimated technical achievements of EERE's R&D programs and their estimated market penetration as inputs. The resulting differences in U.S. petroleum consumption and the market shares of alternative fuels are two of the three key inputs to the Oil Security Metrics Model.

Even small changes in the price elasticity of petroleum demand can significantly reduce the size of the price shock generated by a given reduction in petroleum supply. It has been estimated that an increase from -0.06 to -0.09 in the short-run price elasticity of petroleum demand by OECD countries could reduce the impact of a 6.2 million barrel per day supply shortfall by \$25 per barrel (Figure 11, from Greene, 2005). Greene, Jones and Leiby (1998) estimated the potential benefits of a doubling of the price elasticities of oil supply and demand. They found that the costs to the U.S. economy of a two-year supply shortfall large enough to double world oil prices would be cut in half if world price elasticities could be doubled. The estimated savings to the

U.S. economy over a 17-year period as a result of doubling the elasticities was \$750 billion (2000 \$).



**Figure 11. Effect of OECD Short-run Oil Price Elasticity on Price Shock Impacts of Oil Supply Disruptions**

The new levels of U.S. petroleum consumption and the new price elasticity parameters resulting from the impacts of DOE R&D are used to recalibrate the U.S. oil demand equation in the oil market simulation model, previously calibrated to the relevant AEO scenarios and default elasticity assumptions. Changes in price elasticities over time are accomplished by trending the price slope (b) parameters to values that match the estimated price elasticity in a specified future year. For example, if EERE program goals called for initial mass market commercialization of a technology in 2010, and 10 years were allowed for full market penetration and ten more years for full stock turnover, the price slope would be linearly interpolated from the initially calibrated value to the value that produced the new elasticity over the period 2010 to 2030. Given the new U.S. demand equation, the oil market simulation model is re-solved to produce new paths for U.S. and world oil supply and demand, and the price of oil. The new U.S. oil consumption paths and the new oil demand price slopes are then passed to the oil cost model. The result is an estimate of the impacts of EERE's R&D programs, in a particular AEO projection not including the possibility of oil supply disruptions, and not incorporating uncertainty in parameter values and other key assumptions. Costs are estimated assuming two different assumptions about the response of the OPEC cartel to the changes in U.S. oil demand.

## 6.1 THE COMPONENTS OF OIL SECURITY COSTS AND BENEFITS

Four categories of costs and benefits are estimated.

1. Direct oil savings
2. Transfer of wealth savings

3. Consumers' and producers' surplus benefits
4. Disruption cost savings
5. Optional SPR savings

Transfer of wealth is also a metric of the availability of surplus funds to oil producing states that some have argued are potentially destabilizing and may create problems for U.S. national security.

### 6.1.1 Direct Oil Savings and Transfer of Wealth

Advanced technologies and fuels can reduce the quantity of oil consumed and increase the price elasticity of oil demand. Savings are generated not only because less oil must be purchased but because the world price of oil will likely decrease. A lower price for oil yields savings on every barrel of oil purchased. Total direct oil savings (TDOS) from EERE technologies are calculated by subtracting the discounted present value of oil expenditures in the EERE-impacted Scenario from the discounted present value of oil expenditures in the Base Scenario.

$$TDOS = \sum_{t=2005}^{2030} \frac{Q_{Base,t} P_{Base,t}}{(1+r)^{t-2005}} - \sum_{t=2005}^{2030} \frac{Q_{EE,t} P_{EE,t}}{(1+r)^{t-2005}} \quad (4)$$

The transfer of wealth, as shown in Figure 6, equals the difference between the actual market price and the competitive (or undisrupted) market price multiplied by the actual quantity of oil imported.

$$WT = (P_1 - P_0) \left( Q_1^D - Q_1^S \right) \quad (5)$$

Total direct cost and wealth transfer savings overlap, so that both cannot be counted in the same benefits measure. The reduction in wealth transfer will be smaller than the total direct oil savings because it pertains only to imports. Although wealth transfer is computed as the difference between the actual price of oil and the hypothetical competitive market oil price, as long as the competitive oil price is the same in disrupted and undisrupted scenarios, this will not affect the estimation of security benefits.<sup>10</sup> Total wealth transfer savings are likewise the discounted present value of the future stream of wealth transfer in the Base case minus that in the EERE-impacted case.

An important assumption for estimating the transfer of wealth is the hypothetical competitive market price of oil. Fortunately, several researchers have estimated at different points in time what the price of oil would have been had world oil markets been competitive. Griffen and Vielhaber (1994) put the competitive market price at \$8.20/bbl (in 2000 dollars). Other estimates include Adelman's (1989) \$7.10 (all prices in 2000 dollars), Morison's (1987) range of \$7.10 to \$8.70, and Brown's (1987) range of \$9.60 to \$12.60/bbl. A simulation of competitive oil market conditions by Berg, Kverndokk and Rosendahl (1997) concluded that had OPEC acted as a competitive producer the price of oil in 2000 would have been \$12.10. Historically, the price of

<sup>10</sup> An exception would be if the actual world oil price fell below the hypothetical competitive world oil price. However, this is unlikely if the competitive oil price is in the range of \$10-\$15 per barrel.



imported oil to U.S. refiners was \$10.67/bbl in 1972, the year before Arab members of OPEC first used their market power to cause the oil price shock of 1973. It had been relatively stable though declining slightly in the previous years. The lowest annual oil price on record since 1973 is \$12.48/bbl, in 1998. Modelers' estimates and the historical evidence point to a competitive oil price below \$13.00/bbl, even today.

The chief argument in favor of a stable or falling competitive oil price over the 1970-2004 period is the progress of technology. The International Energy Agency has pointed out that "Oil supply costs have fallen considerably in the last 20 years." (IEA, 2001, p. 52) Technological progress has outpaced depletion thanks to advances such as 4D seismic imaging, increased application of computing power to data acquisition and analysis, technological advances in offshore (especially deepwater) drilling, and application of intelligent, multi-directional drilling technology. In the same report, the IEA presented estimates of current total oil supply costs that ranged from \$4/bbl for major Middle East producers to \$6-\$11/bbl for the major international oil companies (IEA, 2001, figure 2.5). Total oil supply costs include direct lifting costs, production costs and finding and development costs. Other factors enter into the determination of competitive market prices, including transportation and the different qualities crude oils from different sources. Still, it would be hard to imagine how the marginal cost of oil in a competitive market today could exceed \$15/bbl, if the IEA cost estimates are accurate. A default competitive oil price of \$13/bbl is assumed, although the spreadsheet simulation model permits different values to be specified, as well as a time trend to be added.

### **6.1.2 GDP Impacts**

The energy economics literature has addressed the relationship between the price of oil and the GDP at length. Three key issues for estimating the costs of oil dependence addressed in this literature are: (1) the size of oil price's impact on U.S. GDP, (2) whether this impact has been changing over time, and (3) how to define a price shock. There should be little controversy about whether oil price shocks reduce U.S. GDP. Jones, Leiby and Paik (2004) comprehensively reviewed the recent literature on whether and how oil prices affect the economy, with particular attention to the mechanisms through which oil price shocks affect GDP, the effects of monetary policy, and the stability and magnitude of the oil price-GDP relationship. They concluded that post oil shock recessionary movements of GDP are primarily due to the oil price shocks themselves and not changes in monetary policy made to accommodate the shocks. Based on their comprehensive review of the literature Jones, Leiby and Paik (2004) put forward -0.055 as the best consensus estimate of the elasticity of GDP with respect to a price shock, where a shock is defined as a price increase that exceeds a three-year high.

The elasticity of GDP with respect to the price of oil is a useful summary measure of the sensitivity of the economy to oil price shocks. Statistical estimates of the relationship between GDP and oil price depend to a degree on how researchers define an oil price shock. The earliest studies simply used the price of oil. Over time, researchers discovered that the economy responded asymmetrically to oil price increases and decreases, which contributed to instability in the relationship between GDP and oil prices over time. Mork (1989) offered the first asymmetric specification of an oil price shock by using different variables to represent price increases and decreases. Lee, Ni and Ratti (1995) used a measure of the surprise content of the oil price change, which they believed yielded a stable oil price-GDP relationship. Their measure divided the change in oil price by an index of the recent volatility of oil prices, thereby diminishing

shocks occurring in a period of volatility. Hamilton (1996) created a new variable he called the Net Oil Price Increase (NOPI), defined as the difference between the percent increase in a current period and the highest percent increase in the previous four quarters. Hamilton and Herrera (2001) found that both Lee, Ni and Ratti's measure and NOPI had stable relationships with GDP over time, but that the simple price of oil and Mork's measure did not.

In our view, the asymmetric response of the economy to oil price changes is largely due to the two different mechanisms by which oil prices affect GDP: (1) loss of potential GDP, and (2) macroeconomic adjustment costs.<sup>11</sup> The first type of cost is incurred whenever oil prices are raised above competitive market levels. The second occurs only in the event of a price shock. When there is a sudden, unanticipated price increase, both types of cost have a negative impact on the economy. When prices suddenly fall the economy benefits from an increase in potential GDP and a reduction in the transfer of wealth but still suffers adjustment costs. The positive effect may substantially or entirely offset the negative effect of the (downward) price shock. As Huntington (2002, pp. 5-6) has put it, "If both positive and negative energy price shocks create short-run unemployment as resources shift from one sector to another, these shifts between sectors could dampen and even eliminate the otherwise positive effect resulting from a sudden energy price decline." Moreover, the dynamics of the two types of costs are different. The adjustment to a price shock may occur over a period of 3 or more years as wages and prices adapt. But adjustment of the economy's capital stock of energy using equipment takes 10 years and often much longer. As a consequence the full impact of oil price shocks on consumers' and producers' surpluses may take a decade or more to be realized. Thus, there should not be a simple, stable relationship between the GDP and a fluctuating price of oil. As will be seen below, modeling each component separately allows for complex patterns of response.

#### 6.1.2.1 Consumers' and Producers' Surplus (Potential GDP) Losses

The consumers' and producers' surplus losses, due to higher oil price, depends on the size of the price change and the slopes of the U.S. supply and demand curves. Assuming linear or approximately linear supply and demand curves, the rule of  $\frac{1}{2}$  can be used to estimate surplus losses.<sup>12</sup>

$$GL = GDPLoss = \frac{1}{2} \left[ (P_1 - P_0) (Q_0^S - Q_1^S) - (P_1 - P_0) (Q_0^D - Q_1^D) \right] \quad (6)$$

The problem of induced consumers' and producers' surplus losses has been addressed in the economics literature. The generally accepted conclusion is that losses outside the market in which the price rise occurs are pecuniary external effects that can be neglected because surplus losses and gains will approximately cancel (e.g., Sugden and Williams, 1980, ch. 10). If markets are competitive, and demand and supply curves are assumed to be linear, not only the total surplus gains and losses but the deadweight losses and gains will cancel. Thus, deadweight losses outside of the oil market would not be considered and the total loss of potential GDP

<sup>11</sup> The transfer of wealth will not necessarily have a negative impact on U.S. GDP. This will depend on whether the outflow of wealth reduces final demand for U.S. output, either permanently or temporarily.

<sup>12</sup> The rule of  $\frac{1}{2}$  states that for linear supply or demand curves the change in social surplus equals one-half times the product of the change in price times the change in quantity, equivalent to a triangular area under the curve with base  $\Delta P$ .

could be reasonably approximated by the consumers' and producers' surplus losses in the oil market alone.

Rotemberg and Woodford (1996) and Huntington (2002) have produced simulations that illustrate how market power in the economy can magnify the economic impacts of oil price shocks by permitting producers to increase prices beyond the levels that perfect competition would allow (Jones, Leiby and Paik, 2004). Huntington (2002) notes that in an economy with substantial imperfect competition, the impacts of oil price shocks are magnified because, (1) the economy begins at a position where prices exceed marginal costs and moves to a new position in which prices exceed marginal costs by an even greater amount, thereby adding to the welfare losses, and (2) the economy-wide effect of the higher noncompetitive prices is to reduce aggregate demand, a fact not considered by any individual firm and therefore a pecuniary externality and a source of additional economic inefficiency. Furthermore, over the very large price changes experienced in the oil market, the use of linear supply and demand curves may not accurately estimate surplus losses. For this reason, the Oil Security Metrics Model allows a multiplier to be specified that inflates oil market surplus losses by a fixed amount. A default multiplier of 1.5 is assumed, but can be readily changed.

Producers' and Consumers' surplus losses for dynamic, lagged adjustment supply and demand functions can be calculated by integrating under the curves with respect to the weighted sum of past and current oil prices. It is not appropriate to integrate simply with respect to the current price, because the entire history of prices affects the current levels of supply and demand. To find the appropriate price variable, we expand the lagged adjustment model by continuously substituting for the lagged dependent variable,  $Q_{t-1}$ .

$$\begin{aligned} Q_t &= \lambda a_t + \lambda b P_t + (1 - \lambda) Q_{t-1} = \lambda(a_t + b P_t) + (1 - \lambda)(\lambda(a_{t-1} + b P_{t-1}) + (1 - \lambda) Q_{t-2}) = \\ &= \lambda \sum_{i=0}^{t-1} (1 - \lambda)^i a_{t-i} + \lambda b \sum_{i=0}^{t-1} (1 - \lambda)^i P_{t-i} + (1 - \lambda)^t Q_0 \end{aligned} \quad (7)$$

The intercept,  $a_t$ , is indexed by  $t$  to indicate that factors other than the price of oil have been changing over time and affecting the level of demand (or supply). The  $a_t$  are unobserved, but the weighted sum of the  $a_t$ 's plus the lagged effect of  $Q_0$  can be calculated using  $Q_t$ ,  $b$ ,  $\lambda$ , and the historical prices. Let  $K_t$  be the sum of the other effects in year  $t$  based on historical prices, and  $k_t$  represent the effects assuming a competitive oil price of  $P_0$ .

$$K_t = Q_t - b\lambda \sum_{i=0}^{t-1} (1 - \lambda)^i P_{t-i} = \lambda \sum_{i=0}^{t-1} (1 - \lambda)^i a_{t-i} + (1 - \lambda)^t Q_0 \quad \text{and} \quad k_t = Q_t - b\lambda \sum_{i=0}^{t-1} (1 - \lambda)^i P_0 \quad (8)$$

Next, a weighted-sum price variable,  $\Pi$ , can be defined to represent the cumulative effects of current and past prices on demand (or supply).<sup>13</sup>

<sup>13</sup> Allowing the price slope to vary over time would require knowledge of how it varied in order to calculate the weighted price variable. Assuming a constant price slope eliminates this need but at some loss of generality.

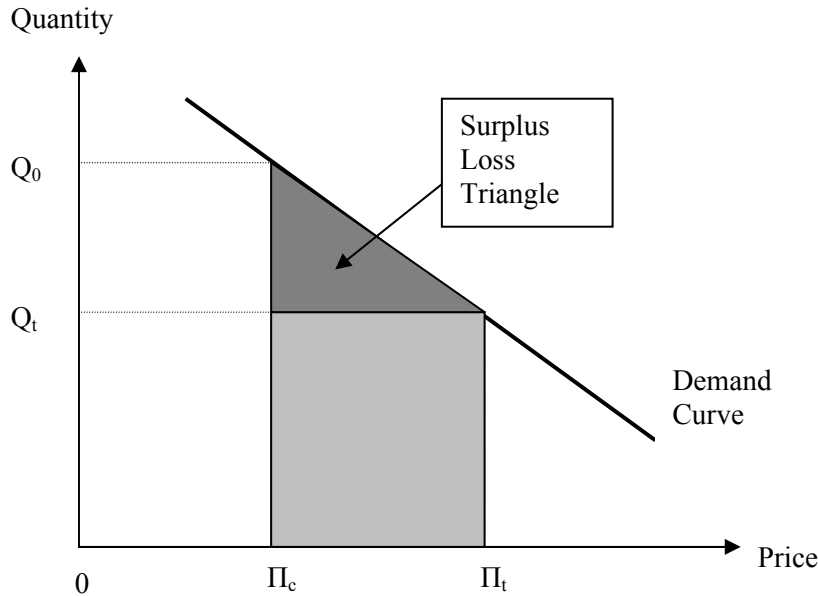
$$\begin{aligned}
\Pi_t &= \lambda P_t + (1 - \lambda) \Pi_{t-1} = \lambda \sum_{i=0}^{t-1} (1 - \lambda)^i P_{t-i} \\
\text{and } \Pi_{ct} &= \lambda P_{ct} + (1 - \lambda) \Pi_{ct-1} \\
\text{and if } P_c \text{ is constant, } \Pi_c &= \lambda P_c + \lambda \sum_{i=0}^{t-1} (1 - \lambda)^i P_c = P_c
\end{aligned}
\tag{9}$$

With these definitions the demand or supply function for petroleum can be written as a function of the weighted average of past prices,  $\Pi$ , and integrated from any arbitrary alternative price series (including constant price,  $P_c \rightarrow \Pi_c$ ) to the actual price series,  $\Pi_t$ . Consumers' surplus is the area under the demand curve from  $\Pi_c$  to  $\Pi_t$ , minus the change in expenditures calculated using  $\Pi$ s instead of actual prices. Producers' surplus is the change in revenues minus the area under the supply curve from  $\Pi_c$  to  $\Pi_t$ .

$$\begin{aligned}
\text{Surplus}^* &= \int_{\Pi_c}^{\Pi_t} (K_t + b\Pi) d\Pi - Q_t(\Pi_t - \Pi_c) = \left( K_t \Pi + \frac{1}{2} b \Pi^2 \right) \Big|_{\Pi_c}^{\Pi_t} - Q_t(\Pi_t - \Pi_c) \\
&= \left( K_t \Pi_t + \frac{1}{2} b \Pi_t^2 - K_t \Pi_c - \frac{1}{2} b \Pi_c^2 \right) - Q_t(\Pi_t - \Pi_c) \\
&= \left[ K_t + \frac{1}{2} b(\Pi_t + \Pi_c) - Q_t \right] (\Pi_t - \Pi_c) \\
&= \left[ Q_t - b \Pi_t + \frac{b}{2} \Pi_t + \frac{b}{2} \Pi_c - Q_t \right] (\Pi_t - \Pi_c) \\
&= -\frac{b}{2} (\Pi_t - \Pi_c)^2 = -\frac{1}{2} ((Q_t - K_t) - (Q_c - K_c)) (\Pi_t - \Pi_c) \\
&= -\frac{1}{2} (Q_t - Q_c) (\Pi_t - \Pi_c) \quad \text{if } K_t = K_c
\end{aligned}
\tag{10}$$

This is directly analogous to the familiar surplus triangle under the demand (or supply) curve defined over the  $\Pi$  axis (Figure 12).<sup>14</sup>

<sup>14</sup> The final step in equation (4) requires the assumption that  $K_t = K_c$ . This implies that the factors other than price affecting demand over time would have evolved in the same way under either price trajectory. By using the formula  $-\frac{1}{2}b(\Pi_t - \Pi_c)^2$  instead, this assumption is not necessary.



**Figure 12. Estimation of Surplus Loss by Integrating Demand Curve over Weighted Price Variable**

This surplus measure is numerated in dollars, since the variable of integration,  $\Pi$ , is a convex combination, i.e., a weighted average of past prices.

The key uncertainties regarding this method are the price elasticities (price slopes) of supply and demand, and the lagged adjustment rate parameters ( $\lambda_{\text{demand}}$ ,  $\lambda_{\text{supply}}$ ). Estimates of these parameters based on the economic literature are discussed in the appendix.

The measure of program benefits is the total discounted present value of potential GDP losses in the base case minus the total discounted present value of losses in the EERE-impacted case.

#### **6.1.2.2 Oil Price Shock Disruption Costs**

The simple notion of macroeconomic disruption costs is that they arise when a sudden price shock throws the economy out of equilibrium. As a result, wages and prices are not able to adjust rapidly enough and underemployment of labor and capital results. Whenever prices are fluctuating a dynamically adjusting economy may be in “equilibrium” with a price that is different from the current market price. This implies that price shocks should be measured relative to an unobserved price to which the economy has dynamically adjusted at the time the price shock occurs. Thus, it should not be the change in the price of oil from the previous year that determines the macroeconomic adjustment impact, but rather the difference between the current price and the price to which the economy has become adjusted in the current year.

The “adjusted prices” used to estimate macroeconomic costs are derived from the concept of the linear lagged adjustment model in which the observed change in a dependent variable from  $t-1$  to  $t$ ,  $X_t - X_{t-1}$ , is assumed to be some fraction,  $1 > \lambda > 0$ , of the difference between the ideal, long-run level at price  $P_t$ ,  $x_t$ , and last period’s actual demand.

$$\begin{aligned}
X_t - X_{t-1} &= \lambda(x_t - X_{t-1}) \\
x_t &= a + bP_t
\end{aligned}
\tag{11}$$

Substituting the second equation into the first and solving for  $X_t$ , one gets the familiar lagged adjustment demand equation.

$$X_t = \lambda a + \lambda bP_t + (1 - \lambda)X_{t-1} \tag{12}$$

Long-run demand is a function of the price level,  $P_t$ , sensitivity to price represented by the parameter  $b$ , and other factors represented by  $a$ .<sup>15</sup> Another way of interpreting the lagged adjustment model is that for the current value of  $X_t$  there exists a price,  $p_t$ , such that  $X_t$  is the long-run equilibrium level of demand at  $p_t$ . Substituting  $p_t$  for  $P_t$  in the second equation of (11), noting that at  $p_t$ ,  $x_t = X_t$ , setting the resulting expression equal to equation (12) and noting that  $X_{t-1} = a + bp_{t-1}$ , produces the following intuitive result.

$$\begin{aligned}
a + bp_t &= \lambda a + \lambda bP_t + (1 - \lambda)(a + bp_{t-1}) \\
p_t &= \lambda P_t + (1 - \lambda)p_{t-1}
\end{aligned}
\tag{13}$$

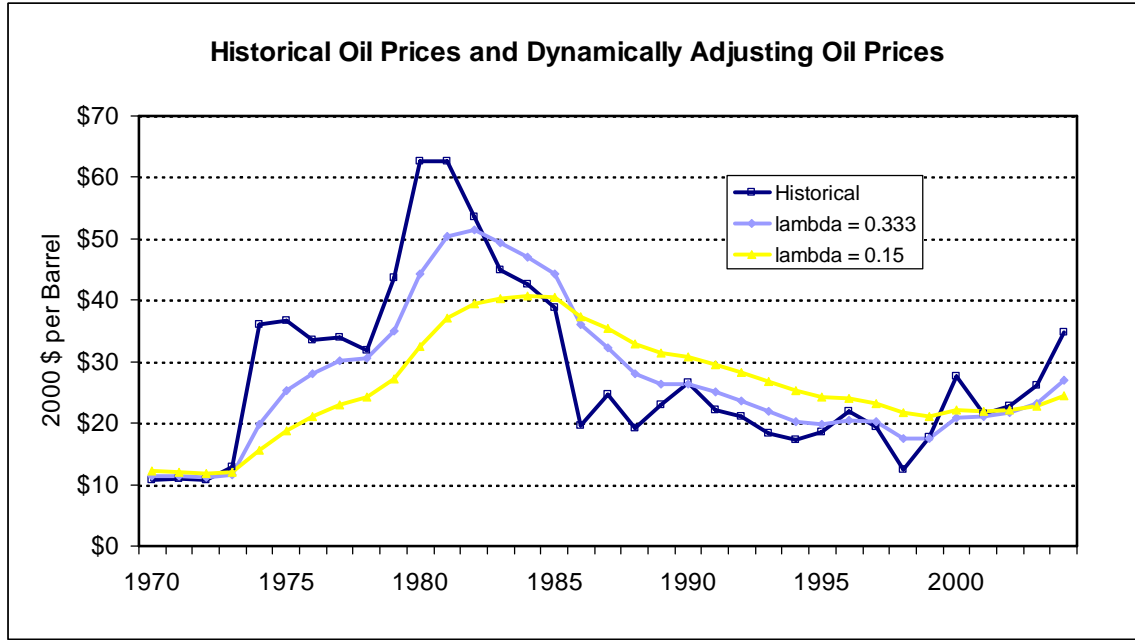
The current adjusted price is a weighted average of the current period's actual price and last period's adjusted price. A starting value for the adjusted price must be chosen,  $p_0$ , but since oil prices were quite stable prior to 1973 it should be a reasonable approximation to assume that  $p_0 = P_{1972}$ .

Figure 12 shows the relationship between the current price of oil and the macroeconomic “adjusted price,” assuming  $\lambda = 0.33$ . Even in the first year of a price shock (e.g., 1974), some adjustment occurs, so that the difference between the current price and the adjusted price is somewhat smaller than that between the current price and the previous year's price. However, in the year after the price shock (1975) there is still a substantial difference between the current price and the adjusted price although there is almost no difference between the actual price in 1975 and the actual price in 1974. Interestingly, the small price shock in 1990 would have no immediate macroeconomic effect since the adjusted price equaled the current price in that year. A much more slowly adjusting price path with  $\lambda = 0.15$  is also shown in Figure 13. This path is indicative of the rate at which potential GDP losses adjust to price changes.

Price shock disruption losses are estimated using a scaled oil price elasticity of GDP,  $\delta$ . The elasticity is scaled by the current year oil expenditure “share” of GDP relative to that of a base year to which the estimated elasticity applies, in this case 1983. This formulation follows Huntington's guidance that, “Economic theory suggests strongly that, in the absence of major threshold effects, the direct response of the GDP and price levels to oil price changes should be proportional to oil's value share in total output.” (Huntington, 2005, p. 43)

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<sup>15</sup> Allowing other factors to vary over time leads to a more complicated formula for the “adjusted price.” If other factors are changing slowly, year-to-year price changes are large, and adjustment is relatively rapid, the simplified formula should be a reasonable approximation.



**Figure 13. Historical Oil Prices and Dynamically Adjusting Oil Prices**

$$SL_t = ShockLoss_t = GDP_t \left( \frac{P_t}{p_t} \right)^{\delta \frac{P_t Q_t / GDP_t}{P_o Q_o / GDP_o}} = GDP_t \left( \frac{P_t}{p_t} \right)^{\delta \frac{GDP_o P_t Q_t}{GDP_t P_o Q_o}} \quad (14)$$

Huntington (2005) concludes that recent studies of the impacts of price shocks on GDP have reached a consensus that price movements must be both rapid and unexpected to cause adjustment losses. This conclusion is also supported by the review of recent literature by Jones, Leiby and Paik (2004). Equation (14) will estimate small shock losses even for gradual, continuous price movements. This deficiency can be mitigated by requiring that the price ratio ( $P_t/p_t$ ) exceeds a threshold value ( $1 + \theta$ ) for a price shock to have occurred. The threshold price ratio,  $\tau$ , is defined as follows.

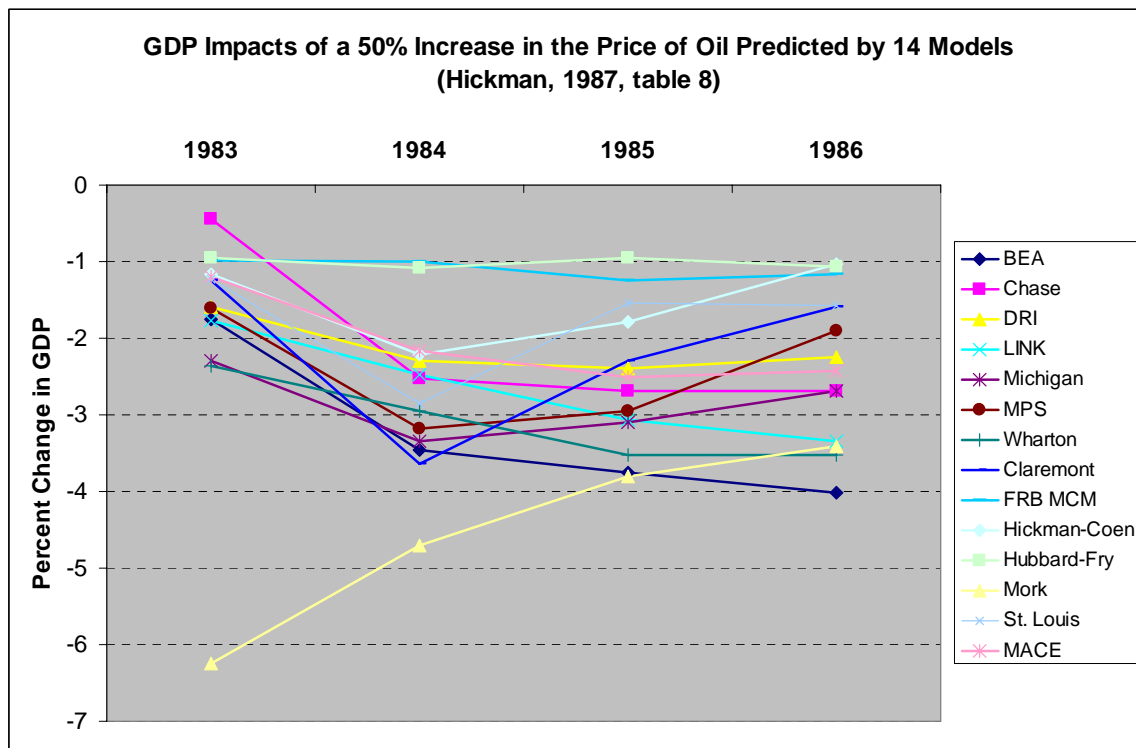
$$\tau = \frac{P_t}{p_t} \quad \text{if} \quad P/P_A \geq 1 + \theta$$

$$= 1 \quad \text{otherwise.} \quad (15)$$

The default value chosen for  $\theta$  is 0.05, but different values can be readily specified, either manually or in simulation runs by specifying a probability distribution for  $\theta$ .

Macro-economic models used to estimate the impacts of oil price shocks on GDP generally predict a greater impact in the year following the initial price shock than in the year in which the

shock actually occurs. According to Jones, Leiby and Paik (2004, p. 13)<sup>16</sup>, “...virtually all empirical studies have found the largest impacts of oil prices on output in the 3<sup>rd</sup> and 4<sup>th</sup> quarters, and continued effects in later quarters.” This appears to be the result of various lags in the economy’s response to oil price changes. For some models, impacts then decay in succeeding years. The Energy Modeling Forum compared the predictions of GDP impacts from 14 different macroeconomic models, given a 50% increase in oil price starting in 1983 and persisting indefinitely (Hickman, 1987). The majority predicted a substantially greater impact in the second year of the price increase, as illustrated in Figure 14.



**Figure 14. Distribution of Oil Price Impacts on GDP over Four Years**

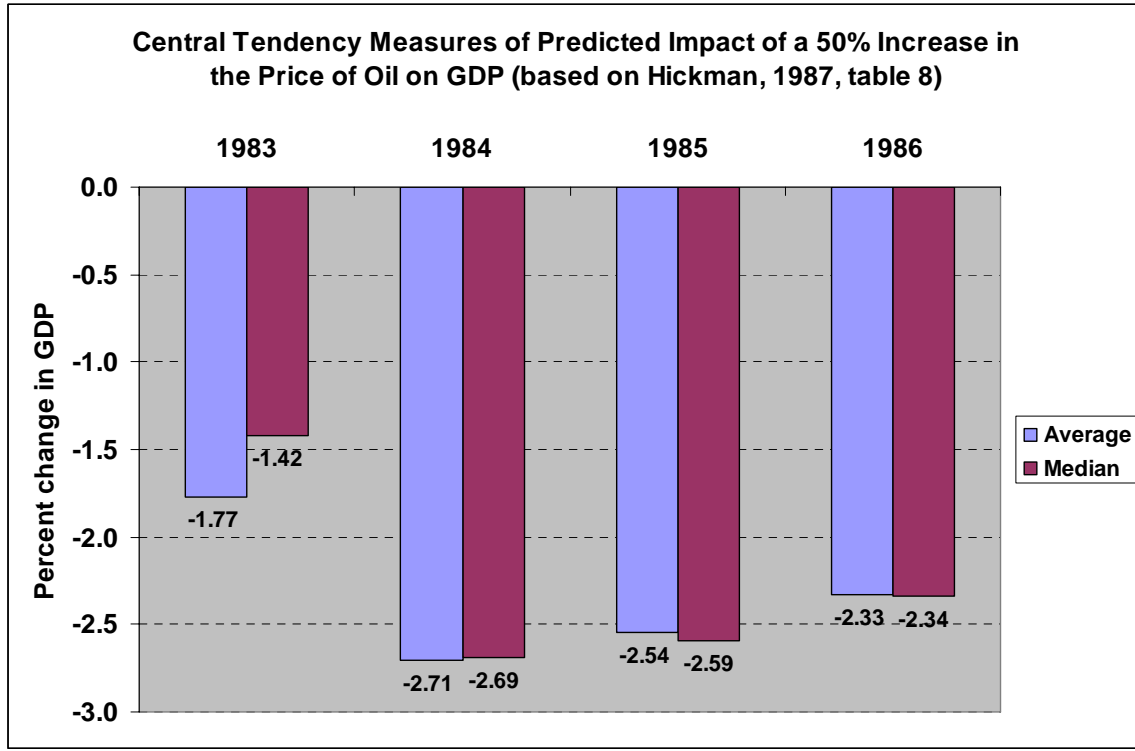
It is important to keep in mind that these models are representing, in theory, the combined macroeconomic adjustment and potential GDP effects. Since we are estimating potential GDP losses independently, only a fraction of the total GDP elasticity should be attributed to macroeconomic costs. However, because oil supply and demand adjusts more slowly than wages and prices, the majority of the oil price impact in the first few years will be due to macroeconomic adjustment costs. As a default, it is assumed that 75% of the maximum, initial GDP impact is due to macroeconomic adjustment costs. Thus, if the overall maximum GDP elasticity is judged to be -0.055, then the maximum macroeconomic adjustment cost elasticity will be -0.04.

A simple average of the model predictions shown in Figure 14 indicates a first-year impact of -1.77% followed by a -2.71% loss of GDP in the second year (Figure 15). The medians of the estimated first- and second-year impacts are -1.42% and -2.69%, respectively. Thus, the models

<sup>16</sup> The literature review by Jones, Leiby and Paik (2004) did not include Santini (1994) which also found that energy prices affect GDP most strongly with a 1-year lag.



tend to predict that somewhere between half and two-thirds of the maximum second year impact is felt in the first year.



**Figure 15. Average Predicted Impacts of Oil Price on GDP over Four Years**

The cost estimation methodology has been modified to reflect the lagged behavior exhibited by the majority of models tested by Hickman (1987). The new equation for the oil price elasticity of GDP is the following (abs( ) indicates the absolute value function).

$$MAC = \lambda \left[ abs \left( 1 - \left( \frac{P_t}{p_t} \right)^{0.75 \beta \left( \frac{\phi_t}{\phi_{1983}} \right)} \right) GDP_t \right] + (1 - \lambda) \left[ abs \left( 1 - \left( \frac{P_{t-1}}{p_{t-1}} \right)^{0.75 \beta \left( \frac{\phi_{t-1}}{\phi_{1983}} \right)} \right) GDP_{t-1} \right] \quad (16)$$

In equation (16)  $\beta$  is the second-year, maximum oil price elasticity of GDP,  $\phi_t$  is the oil cost share of GDP in the current year ( $\phi_{1983}$  is the reference year in which  $\beta$  is assumed to apply),  $P_t$  is the actual price of oil in year  $t$  while  $p_t$  in the denominator is the price to which the economy has adjusted, and  $\lambda$  is the fraction of the maximum macroeconomic adjustment impact assumed to occur in the first year. The data presented above suggest that  $\lambda$  is approximately 0.55.

## 6.2 A READILY CALIBRATED WORLD OIL MARKET MODEL

A simplified representation of the world oil market is constructed by dividing the world into two demand regions (United States and ROW) and three supply regions (United States, ROW-non-OPEC, OPEC). The model is comprised of linear lagged adjustment equations for U.S. oil

demand, U.S. domestic supply, world oil demand and ROW (non-OPEC) oil supply, following the method of Greene, Jones and Leiby (1995). OPEC supply is exogenous, initially as specified in the respective AEO forecast.

The linear lagged adjustment model assumes that the change in demand  $_dQ_t$  or supply  $_sQ_t$ , from period  $t-1$  to  $t$  is a fraction ( $0 < \lambda < 1$ ) of the difference between the long-run equilibrium demand (supply)  $q_t$  that would prevail at price  $P_t$ , and last year's demand (supply). The equations for supply and demand are structurally identical, so the  $d$  and  $s$  subscripts are omitted in the equations below.

$$\begin{aligned} Q_t - Q_{t-1} &= \lambda(q_t - Q_{t-1}) \\ q_t &= a_t + bP_t \end{aligned} \tag{17}$$

The constant term,  $a_t$ , represents factors other than price that determine a region's petroleum demand (supply). The subscript  $t$  indicates that these factors generally vary over time, and thus there can be a different intercept term for each year. Substituting for  $q_t$  in the lagged adjustment equation and solving for  $Q_t$  produces a simple equation for  $Q_t$  as a function of price, lagged demand (supply) and the parameters  $a_t$ ,  $b$  and  $\lambda$ .

$$Q_t = \lambda a_t + \lambda b P_t + (1 - \lambda) Q_{t-1} \tag{18}$$

Calibration of the simple oil market model is accomplished automatically within the spreadsheet. The parameters  $b$  and  $\lambda$  are chosen to match the price elasticity and adjustment rates typical of those used in the EIA's World Oil Market Model and other models (see the appendix). The following equations for short-run ( $\beta_{SR}$ ) and long-run ( $\beta_{LR}$ ) price elasticities are used to calibrate price slopes for the first forecast year.  $Q_o$  and  $P_o$  are reference quantity and price levels for calibration.

$$\beta_{SR} = b\lambda \frac{P_o}{Q_o} \quad , \quad \beta_{LR} = b \frac{P_o}{Q_o} \tag{19}$$

There is considerable evidence that  $\lambda$ 's for petroleum supply and demand are small, on the order of 0.10 to 0.15. As a default, 0.15 is used, but it can be readily changed. Given values for  $b$  and  $\lambda$  for each of the four equations, the model is calibrated to a particular global scenario by solving for multipliers that make the supply and demand equations match the scenario predictions of prices and quantities in each year. Similar multipliers are used to create alternative calibrations for price shock scenarios and for the DOE R&D impacts scenarios.

The following method is used to adjust the U.S. demand curve for changes in the quantity demanded. Let the first year of impact of the DOE's programs be year  $t$ , and let the ratio of DOE-impacted demand in year  $t$  to the base scenario demand be  $f_t$ . A multiplier,  $g$ , is solved for, such that the new U.S. demand for petroleum exactly matches the R&D-impacted demand at the scenario price.

$$\begin{aligned}
f_t Q_t &= \lambda g_t a_t + \lambda g_t b P_t + (1 - \lambda) Q_{t-1} \\
\text{and} \\
f_{t+1} Q_{t+1} &= \lambda g_{t+1} a_{t+1} + \lambda g_{t+1} b P_{t+1} + (1 - \lambda) f_t Q_t
\end{aligned} \tag{20}$$

Solving equation 20 for  $g$  gives the following general relationship.

$$g_{t+1} = \frac{f_{t+1} Q_{t+1} - (1 - \lambda) f_t Q_t}{\lambda a_{t+1} + \lambda b P_{t+1}} \tag{21}$$

Reductions in U.S. petroleum demand over the base scenario due to DOE's R&D programs change the U.S. petroleum demand function. Since the demand curve is linear, changes in the level of demand will affect not only the intercept term but the price slope as well. Since the adjustment rate parameter is determined by the process of capital stock turnover, it is assumed to be unaffected. Detailed equations for calibrating the oil market model and solving for new equilibria are presented in the appendix.

Given a fully calibrated oil market model, market equilibrium given changes in U.S. oil demand and its price elasticity can be calculated by solving the system of linear equations for a new market equilibrium price, and supply and demand quantities.

Find  $P_t$  that satisfies,

$${}_{US}Q_t(P_t) + {}_{ROW}Q_t(P_t) = {}_{US}q_t(P_t) + {}_{ROW}q_t(P_t) + {}_{OPEC}q_t \tag{22}$$

Assuming that all supply and demand functions can be adequately represented by lagged adjustment models, and assuming that all the models share the same lagged adjustment rate parameter,  $\lambda$ , equation X can be expanded in terms of prices and quantities. (It is not necessary to assume that all equations share the same lagged adjustment parameter. That assumption is made here to simplify the exposition and because it is not an unreasonable approximation, in any case.)

$$\begin{aligned}
\lambda_1 A_{US,t} + \lambda_1 B_{US} P_t + (1 - \lambda_1) Q_{US,t-1} + \lambda_2 A_{ROW,t} + \lambda_2 B_{ROW} P_t + (1 - \lambda_2) Q_{ROW,t-1} = \\
= \lambda_3 a_{US,t} + \lambda_3 b_{US} P_t + (1 - \lambda_3) q_{US,t-1} + \lambda_4 a_{ROW,t} + \lambda_4 b_{ROW} P_t + (1 - \lambda_4) q_{ROW,t-1} + q_{OPEC,t}
\end{aligned} \tag{23}$$

Collecting all the terms involving  $P$  on the left-hand side yields,

$$\begin{aligned}
\lambda_1 B_{US} + \lambda_2 B_{ROW} - \lambda_3 b_{US} - \lambda_4 b_{ROW} P_t = \\
\lambda_3 a_{US,t} + \lambda_4 a_{ROW,t} - \lambda_1 A_{US,t} - \lambda_2 A_{ROW,t} \\
+ (1 - \lambda_3) q_{US,t-1} + (1 - \lambda_4) q_{ROW,t-1} - (1 - \lambda_1) Q_{US,t-1} - (1 - \lambda_2) Q_{ROW,t-1} + q_{OPEC,t}
\end{aligned} \tag{24}$$

This leads directly to the equilibrium market price.

$$P_t = \frac{\lambda_3 a_{US,t} + \lambda_4 a_{ROW,t} - \lambda_1 A_{US,t} - \lambda_2 A_{ROW,t} + (1 - \lambda_3)q_{US,t-1} + (1 - \lambda_4)q_{ROW,t-1} - (1 - \lambda_1)Q_{US,t-1} - (1 - \lambda_2)Q_{ROW,t-1} + q_{OPEC,t}}{\lambda_1 B_{US} + \lambda_2 B_{ROW} - \lambda_3 b_{US} - \lambda_4 b_{ROW}} \quad (25)$$

The new market equilibrium price can be entered into the current year supply and demand equations to calculate current year supply and demand quantities. These become the lagged quantities needed to solve the next period's price equation. The entire dynamic system is solved for all time periods by this recursive procedure.

This equation can be used to estimate the market price assuming OPEC maintains its base scenario production schedule in the face of reduce U.S. oil demand and increased price elasticity.

The equation for market equilibrium price can also be used to compute the OPEC production schedule that would maintain the base scenario's price path, by substituting the base scenario price path (designated  $P_t^*$ ) for  $P_t$ , and solving for  $q_{OPEC,t}^*$ .

$$q_{OPEC,t}^* = P_t^* (\lambda_1 B_{US,t} + \lambda_2 B_{ROW,t} - \lambda_3 b_{US,t} - \lambda_4 b_{ROW,t}) - (\lambda_3 a_{US,t} + \lambda_4 a_{ROW,t} - \lambda_1 A_{US,t} - \lambda_2 A_{ROW,t}) - ((1 - \lambda_3)q_{US,t-1} + (1 - \lambda_4)q_{ROW,t-1} - (1 - \lambda_1)Q_{US,t-1} - (1 - \lambda_2)Q_{ROW,t-1}) \quad (26)$$

The Oil Security Metrics Model can be instantly recalibrated to AEO scenarios, and benefits simultaneously computed. The closed-form calibration equations derived above instantly calibrate the world oil market model to any chosen AEO projection, and instantly calibrate a new oil market solution to EERE program impacts. Thus, during a simulation run alternative scenarios can be chosen at random to represent the fact that the future is uncertain. The OSMM allows probabilities to be specified for up to four alternative scenarios. Simultaneously, the benefits of EERE programs are computed under two alternative assumptions about OPEC's response.

### 6.3 OPEC RESPONSE TO REDUCED U.S. OIL DEMAND

Because OPEC is a cartel of sovereign states, there is no simple function, such as a supply curve, that can represent its response to a change in U.S. oil demand. In the oil market model, OPEC production is exogenous. History shows that OPEC's production decisions and the resulting price of oil are not a simple function of its market power (see Figure 3). It also appears that OPEC has not stuck with a single, consistent strategy since its first successful impact on the market in 1973 (Kohl, 2002). How OPEC might respond to significant changes in U.S. oil demand is therefore an open question.

Rather than predicting a single OPEC response to changes in U.S. oil demand, the OSMM attempts to bound the range of plausible responses by OPEC with the following two strategies:

1. OPEC maintains production at the base scenario level, allowing the world oil price to fall or,
2. OPEC maintains the base scenario world oil price by cutting production.

Of course, any intermediate strategy is also possible. If OPEC were to follow strategy 1, the United States would reap economic benefits from the reduced price of petroleum as well as benefits from reduced petroleum use. However, U.S. domestic supply would also decrease as a result of the lower world oil price. If OPEC follows strategy 2, there would be no oil price benefits because the world oil price would remain the same. U.S. domestic supply would be unchanged because the price of oil would be the same and so U.S. imports would fall by the same amount as the reduction in U.S. consumption. As a result, there would be direct savings due to the reduction in oil consumption and the transfer of wealth from U.S. oil consumers to foreign oil exporters would be reduced. The reduction in imports also implies reduced strategic vulnerability, which could be taken in the form of reduced expenditures on the SPR or an increased level of insurance provided by the same size SPR.

The bounding strategies outlined above exclude the following two possibilities. It is assumed that in the event of a *decrease* in U.S. oil demand OPEC would not *increase* production, further driving down the price of oil. Rather than counteracting the effect of decreased U.S. oil demand, such a strategy would amplify it, conferring even greater economic benefits on the United States. The second possibility ruled out is that OPEC would attempt to raise prices even higher than the base scenario level, in spite of reduced U.S. demand and increased price elasticity. By adopting this strategy, OPEC would be attempting to raise prices higher than the base scenario but from a position of diminished market power. Such a strategy might be possible for a time, but would imply either that OPEC's base scenario strategy was not optimal, or that the cartel would be willing to accept lower profits in order to punish the oil consuming economies. It is very likely that this would initiate a downward spiral leading to a price collapse, although the proof of this is left for future analysis.

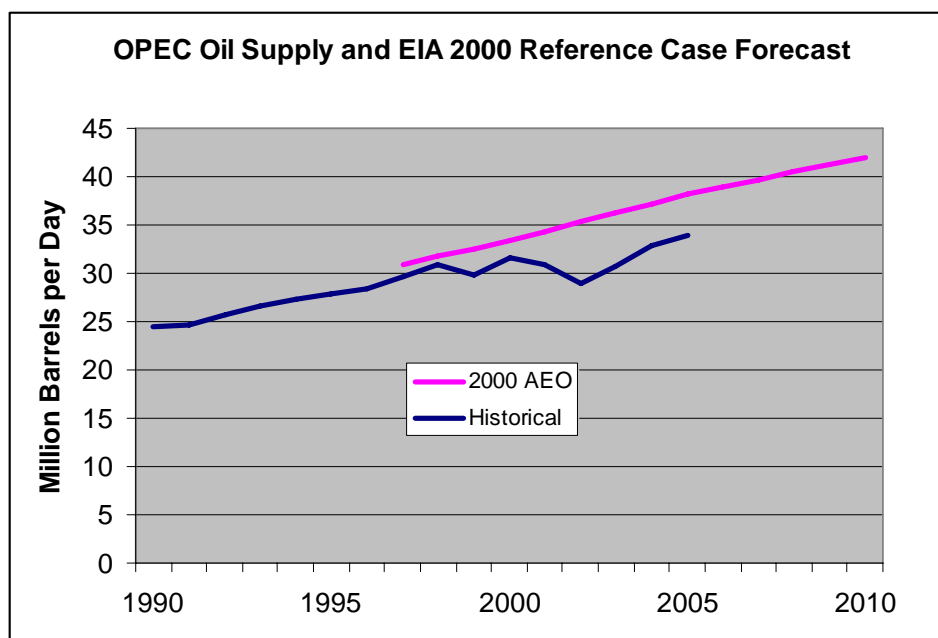
Another potentially important question is whether the rest of the developed and developing economies would follow the U.S. lead in adopting advanced energy efficient technologies. If so, the impacts on world oil markets would be magnified and the oil security benefits to the United States would increase significantly. At present, it is proposed to focus solely on changes within the U.S. economy and assume other economies' oil demands remain unchanged. However, such an assumption is probably not realistic in a global marketplace, and should be reconsidered promptly.

## **6.4 A STOCHASTIC MODEL OF FUTURE OIL PRICE SHOCKS**

Taking account of the likelihood of oil supply shocks leading to price shocks is essential to assessing the potential oil security benefits of DOE programs. Supply shocks are simulated in the OSMM by specifying probabilistic models of the occurrence, duration and magnitude of supply disruptions (e.g., see Beccue and Huntington, 2005). Leiby and Bowman (2000) developed a short-term supply shock model of this type for estimating the optimal size of the SPR. The model used in this study closely follows the structure of their model but is adapted to simulate supply shocks lasting from one to seven years. Price shocks are simulated by sudden, unexpected reductions in petroleum supply from OPEC. Assuming that all lost supply is from OPEC and only OPEC is admittedly a simplification of the causes of real world price shocks. However, all four price shocks since 1970 that lasted a year or more and involved substantial losses of world supply were chiefly the result of losses of supply from OPEC.

In this section a stochastic model of supply shocks is presented and approximately calibrated to the historical record by simple methods. In each year there is a fixed probability that a supply shortfall will be initiated. When a supply shock occurs, a randomly chosen length is also determined. In each year of the price shock a random percent change in OPEC supply is applied. While a supply shock is in progress, another may not begin. Risk analysis software is used to automatically execute the spreadsheet model hundreds or thousands of times, each time generating a new path for future world oil prices. The outputs are probability distributions rather than single point estimates for each cost component. Oil security benefits are estimated by comparing the expected impacts of EERE programs in undisrupted scenarios with the expected benefits from scenarios including the potential for supply shocks.

The history of world oil prices reveals periods of relatively stable prices as well as periods of price upheavals (Figure 2). EIA forecasts, on the other hand, typically reflect smooth price trends (Figure 16). While there are sound reasons for the EIA's excluding oil price shocks from its standard projections (e.g., the unpredictability of the timing and size of shocks, the possibility that forecasted shocks might be misinterpreted, etc.), recent history combined with the likelihood of growing OPEC market share in the future suggests that more realistic price paths should be used to assess the oil security benefits of EERE's R&D programs.



**Figure 16. Comparison of EIA Forecast and Historical OPEC Petroleum Supply**

Sources: <http://www.eia.doe.gov/emeu/ipsr/t44.xls> ; EIA/DOE, 1999, table A.20.

Figure 16 illustrates three key points. First, a supply shock is most appropriately defined as a deviation from the relevant EIA forecast. Second, OPEC supply does not quickly return to the forecasted trend after the supply shock but remains below it for several years if not indefinitely. Third, although it is certainly arguable as to whether the period 1999-2005 shown in Figure 10 contains two price shocks or one, if one assumes a single price shock then one must allow the possibility of increased as well as decreased OPEC supply during a shock.

Price shocks are difficult to predict because they can arise from a variety of causes and because OPEC members may choose to sustain or increase the initial supply shortfall, to counteract it or

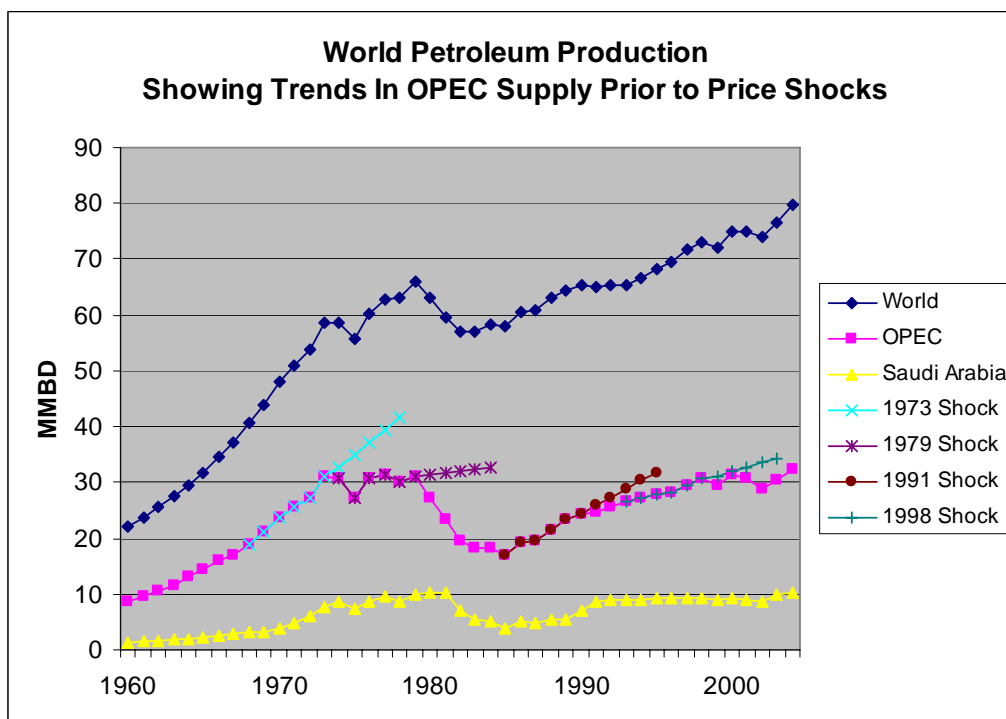
take no action. The four major price shocks of the past three decades are illustrative (Figure 11). The 1973-74 shock was caused by a reduction in oil supplies from Arab OPEC members engaged in an oil boycott against the United States and other countries that gave support to Israel in the 1973 October War. In addition, demand for oil was also growing rapidly at the time: oil consumption increased at an average annual rate of 7.8%/year from 1963 to 1973 (U.S. DOE/EIA, 2005, tables 11.10, 11.15 and 5.21). In 1979-80, the Iran-Iraq War was the proximate cause, but the higher price of oil was supported for five years by continued supply reductions by OPEC, especially Saudi Arabia, which decreased crude oil production from 9.9 mmdbd in 1980 to 3.4 mmdbd in 1985. The shock of 1990-91 was triggered by the Persian Gulf War. However, that shock was short-lived because key OPEC members increased production. Saudi Arabia, in particular, increased crude oil output from 5.1 mmdbd in 1989 to 6.4 in 1990 and to 8.1 in 1991, largely offsetting a 4.2 mmdbd reduction in supply from Iraq and Kuwait over the same period. The price increase of 2000 is believed to have been engineered by OPEC to increase its revenues, while the current price shock appears to be due to a sudden surge in demand combined with limitations on production. Future price shocks likewise might arise from catastrophic events or deliberate actions, could be sustained or curtailed by action of the OPEC cartel, and will be influenced by trends in petroleum demand.

The inability to predict the timing and size of price shocks indicates that a probabilistic model of future price shocks is the appropriate formulation. In the model presented below, price shocks are assumed to be caused solely by reductions in OPEC supply from the respective EIA projection. Recent history indicates that major supply shocks are most frequently caused by an unexpected reduction in supply from OPEC members but that an unanticipated acceleration in demand can also be a contributing factor. In addition, other oil producing states are believed to have acted in concert with OPEC at times, in particular in 2000, magnifying OPEC's market power. Thus, a model based on reductions in only OPEC supply may under-represent the potential for future oil supply shocks.

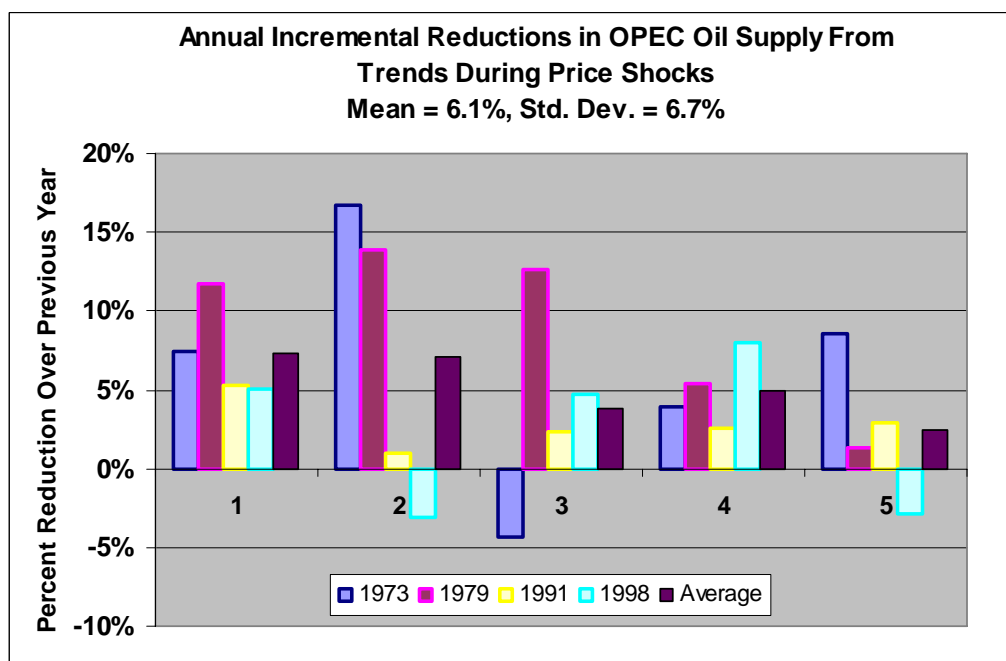
Nevertheless, a supply shock is defined as a deviation from the OPEC production schedule specified by the relevant AEO projection. Actual OPEC supply paths following the four major price shocks of 1970-2000 are compared with linearly extrapolated OPEC production trends in Figure 17. In none of the four cases does OPEC production return to the level of the extrapolated trend. Also, shocks may last several years before OPEC production resumes a generally increasing trend. In general but not always, the gap between the trend line and actual production increases over the duration of the shock. The annual reductions in OPEC supply over a five year period following each of the supply shocks just defined are shown in Figure 18. Reductions in supply are shown as positive numbers. The reductions shown are for a single year and do not represent the cumulative reduction. The data strongly suggest that supply shocks can last several years.

The stochastic price shock model used in the OSMM is similar in structure to the model Leiby and Bowman (2000) developed to investigate the optimal size of the SPR. After 2005, the probability of a supply shock beginning in any given year is assumed to be an independent Bernoulli random variable with constant probability  $p$ . The default assumption is that  $p = 0.15$ . There have been four major price shocks in the 35 years since 1970, although counting supply disruptions as short as two weeks and as small as 0.2 MMBD, Leiby found 19 over the same period (Huntington, 2005). Once a supply shock has occurred, a second supply shock cannot begin until the first has ended. Given that a supply shock has occurred, its length is assumed to

be uniformly distributed over the interval one to seven years. Given these assumptions, Monte Carlo simulations produce an average of 2.7 price shocks over the period 2006-2030, with a standard deviation of 1.1. On average, supply shocks are ongoing in 10 of the 25 years of the forecast, with a standard deviation of 4.5.



**Figure 17. OPEC Supply Trends Prior to Historical Oil Price Shocks**



**Figure 18. Annual Reductions (shown as positive numbers) in OPEC Supply in Years Following Oil Price Shocks**

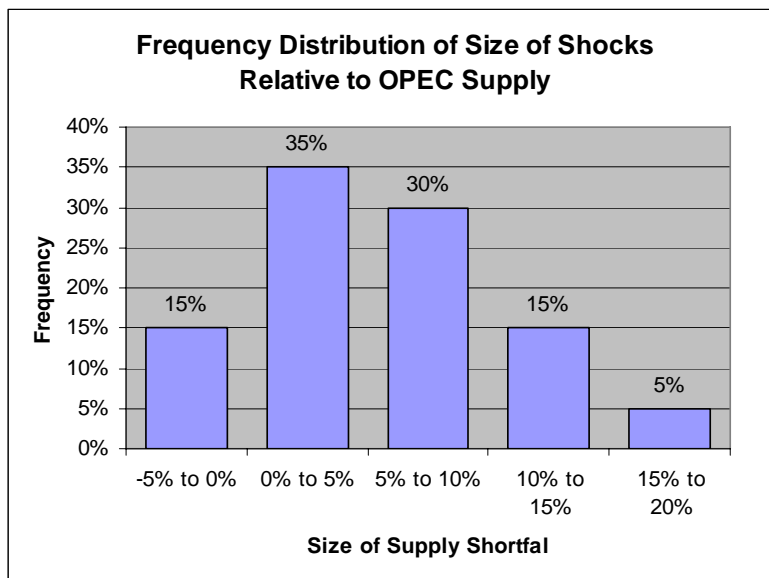


A Delphi study conducted for the U.S. DOE by the Energy Modeling Forum of Stanford University concluded that the probability of future supply shocks had increased between 1996 and 2005 (Beccue and Huntington, 2005). Despite the sound reasons the authors provide for this prediction, in our view the default calibration should be to the historical record.

If one begins counting in 1970, the four major price shocks over a 35 year period imply a ratio of  $4/35 = 0.11$  for the historical record versus  $2.7/25 = 0.11$  for the model. The price shock of 1973-74 appears to have continued for five years, the 1979-80 shock lasted for seven years until the price collapse of 1986, while the 1990-91 and 2000 price shocks appear to have endured for only a single year (compare Figure 4 with Figure 17). This gives 14 years out of 35, or a ratio of 0.4 for shocked years to non-shocked years. This compares with  $10.3/25 = 0.4$  for the model.

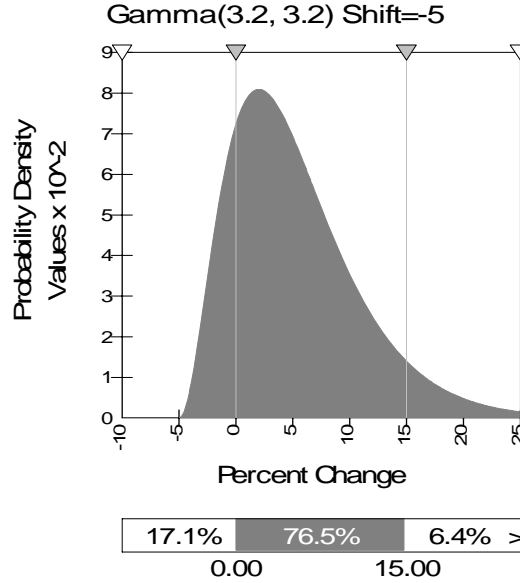
In each year,  $y$ , of a future supply shock, the size of the percent change in OPEC supply,  $\delta_{yt}$ , is assumed to be a Gamma distributed random variable with default parameters  $\alpha = 3.2$  and  $\beta = 3.2$ , and shift parameter = -5.<sup>17</sup> Changes are specified as percentage increases or decreases from the previous year. The shift parameter of -5 insures that no random supply increase can be greater than 5%. The historical data and trend lines shown in Figure 17 produce the distribution of annual price shock changes shown in Figure 19. These are approximated by the Gamma distribution shown in Figure 20.

In the fitted Gamma distribution of Figure 20, 17% of supply changes are increases, while the historical data indicates 15%. In the fitted distribution, 6.4% of changes are greater than 15% reductions; the historical data suggest 5%.



**Figure 19. Historical Distribution of OPEC Supply Changes during Supply Shocks**

<sup>17</sup> Leiby and Bowman (2000) chose the extreme value distribution to represent the size of price shocks. The shape of the extreme value distribution is very similar to the Gamma distribution specified here. The choice of the Gamma over the extreme value is solely based on the fact that the Excel software includes a standard spreadsheet function for the inverse Gamma distribution but not for the extreme value distribution. Otherwise, the extreme value distribution would have been preferred.



**Figure 20. Hypothesized Distribution of OPEC Supply Changes during Future Price Shocks**

Specifying price shocks as a percent of total OPEC supply means that absolute supply reductions will be greatest when OPEC supply is greatest. In the AEO projections, less OPEC production is associated with higher oil price levels and higher OPEC output implies lower price levels. Thus, in the low oil price AEO projections when OPEC output is at its highest levels supply shocks and hence price shocks will tend to be larger than in the high price scenarios in which OPEC production is typically assumed to be at much lower levels. This formulation is consistent with the economic theory of partial monopoly, in which the cartel's market power depends on its share of the market.

Scenarios with supply shocks will generally have higher average price levels than un-shocked scenarios because supply shocks are generally reductions and their impacts accumulate multiplicatively. The “disrupted” supply level in year Y of a price shock is the product of all previous year's supply shock multipliers and the scenario OPEC production level. In years in which there is no shock,  $\delta_t = 0$  and the multiplier is 1.0.

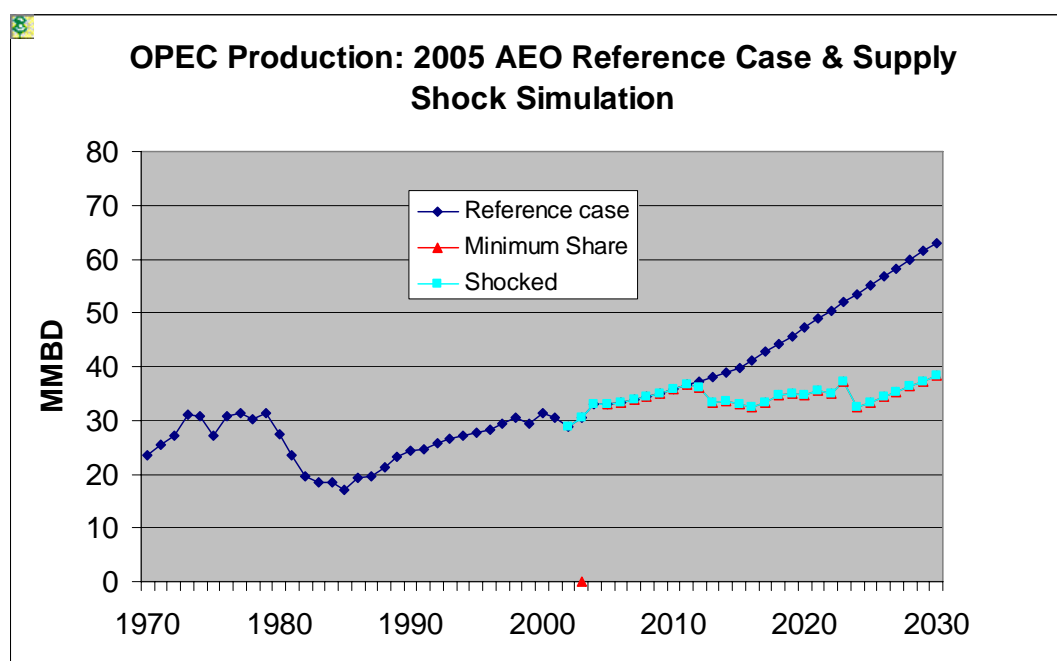
$$q_o^*(t, y) = q_o(t) \prod_{y=1}^Y \left( 1 - \frac{\delta_{yt}}{100} \right) \quad (27)$$

Once a period of supply shocks has ended, OPEC production does not return to the original scenario level; the cumulative effect of past supply shocks persists. However, OPEC supply will resume growing at the rate assumed in the relevant AEO projection. This appears to be consistent with the historical patterns shown in Figure 11. It is possible, but unlikely given the assumed distribution of supply shocks (Figure 14), for a shock to consist of a series of supply increases. In such a case the average world oil prices would actually be lower than the base forecast. It is more likely that a long price shock, say lasting 5, 6 or 7 years, would include mostly reductions in supply but also one or more years in which OPEC supply increased.

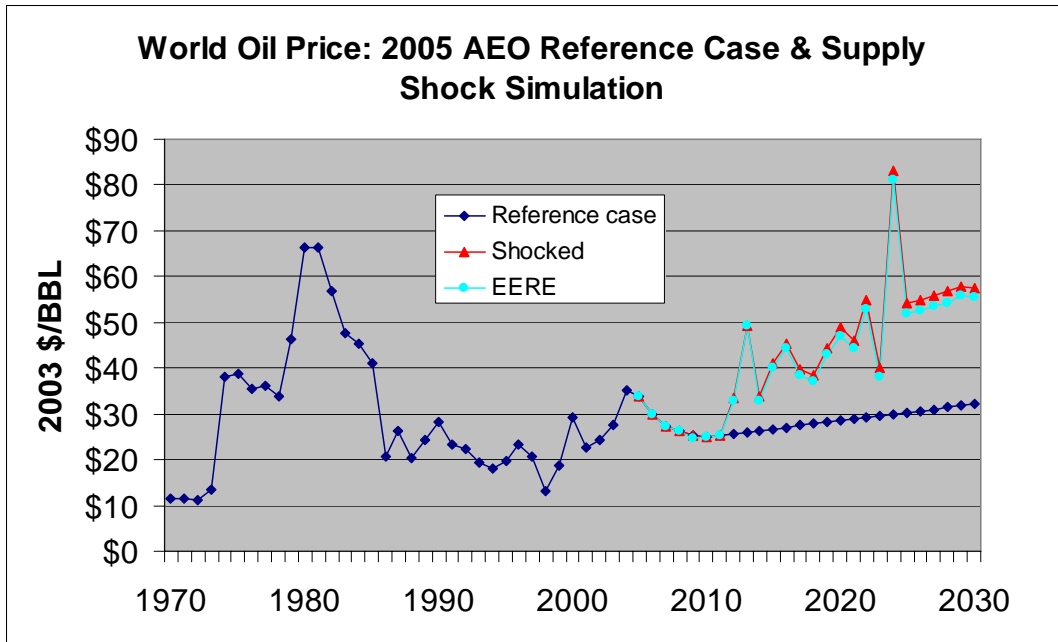
The history of OPEC behavior (as illustrated in Figure 4) suggests there is a limit to the cartel's willingness to sacrifice market share. In 1985 the OPEC core members' share of the world oil market dipped below 25%. In 1986 OPEC members gave up their defense of high oil prices and increased production, producing the oil price collapse of 1986. Maintaining a high oil price over several years requires cutting back on production which entails loss of market share. Because market share is a key determinant of the market power of the cartel, defending too high a price leads eventually to a downward spiral of revenues. This downward spiral will inevitably induce OPEC to abandon the defense of a too high price for oil. This phenomenon is simulated in the oil market model by truncating a supply shock whenever OPEC's previous year's market share falls below 25% (25% is the default value, a different value can be chosen for any particular model run).

Supply shocks create a new OPEC production scenario. By entering the new OPEC production numbers in the calibrated world oil supply model, new market equilibrium prices and quantities can be calculated.

Figures 21 and 22 show one realization of a “shocked” oil supply scenario occurring in the Reference Case projection. There are actually three shock periods: (1) a six year shock beginning in 2012, (2) another six year shock beginning in 2019 in which there is an increase in supply in 2023, and (3) a two year shock beginning in 2030 (only the first year is realized) which begins with an small increase rather than a decrease in OPEC supply. In a typical simulation run, on the order of one thousand different supply shock scenarios are generated and evaluated.



**Figure 21. Reference Case and a Simulation of “Shocked” Oil Supply**

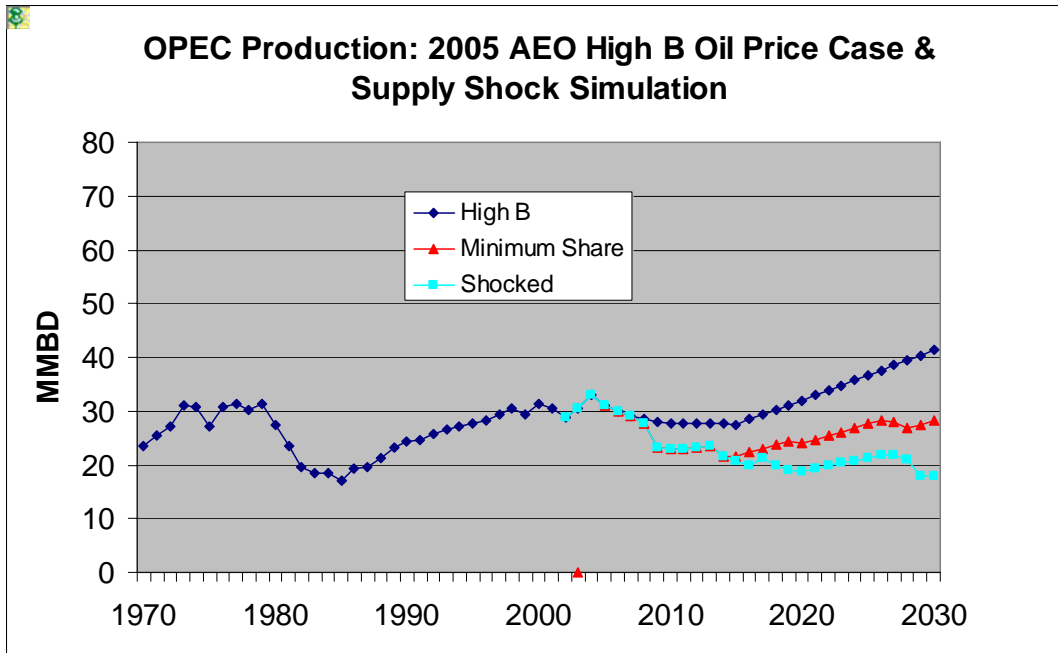


**Figure 22. Reference Case and a Supply Shock Simulation**

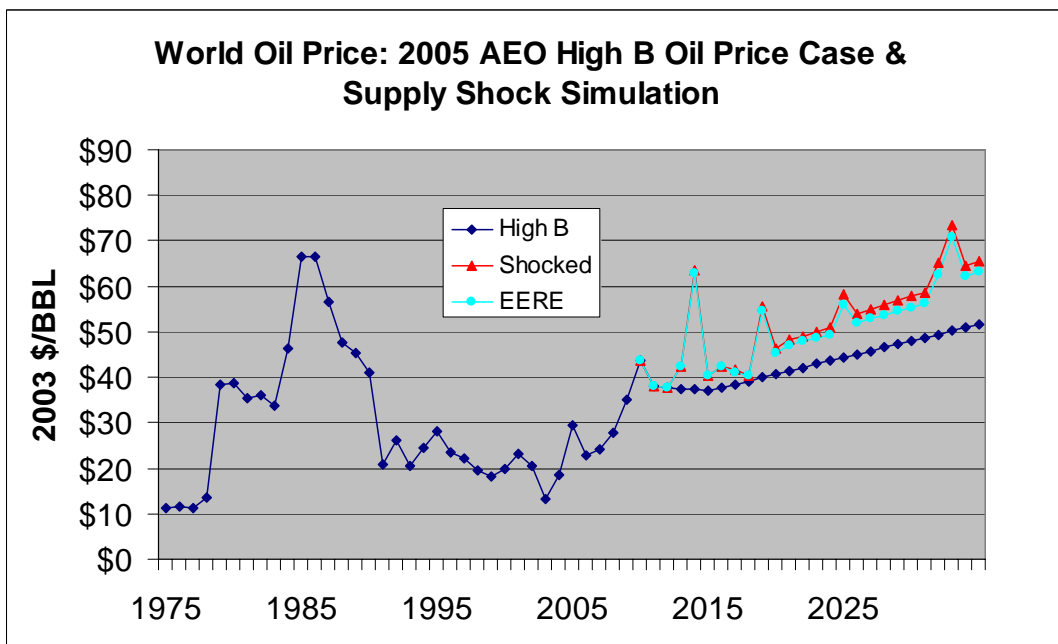
The two six-year shocks keep the price of oil well above the reference case projection through 2030. The shocked price path is strikingly different from the Reference Case projection but looks more like the historical record.

Figures 23 and 24 illustrate a different market share limited supply shock scenario occurring in the High B Oil Price Case. To begin with, OPEC's market share is substantially lower in the High B Case than the Reference Case. The light blue line indicates the uncensored supply shock scenario, while the red line illustrates the market share limited scenario. When the second oil supply shock beginning in 2017 causes OPEC's market share to dip below 25%, it is terminated and OPEC supply begins increasing at the same rate as the original High B Case.

The impact of the simulated supply shocks on world oil prices is illustrated in Figure 24. The price path is only somewhat higher than the High B Oil Price projection in which the supply shocks occur, and it is more variable. Figure 24 also shows the small but perceptible impact of the EERE hybrid vehicle market penetration scenario on world oil price (the price is \$1-\$2/bbl. lower in the EERE hybrid vehicle scenario).



**Figure 23. Market Share Limited Supply Shock in the High B Oil Price Case**



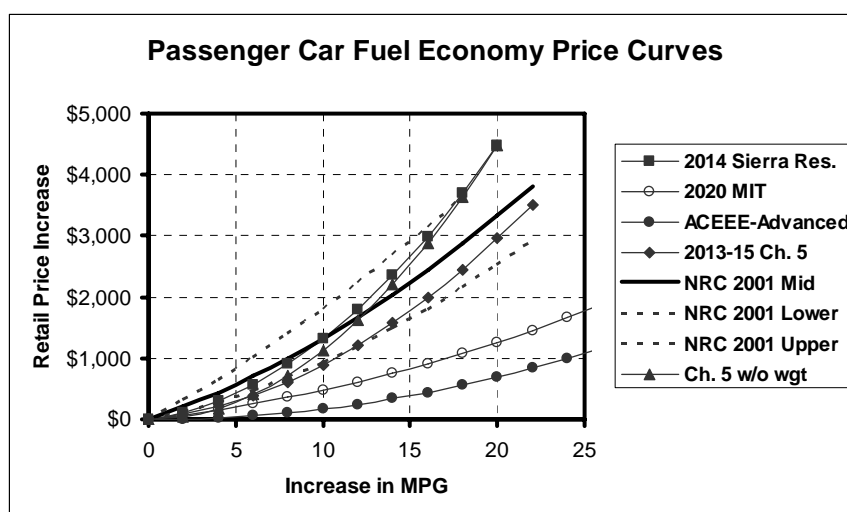
**Figure 24. Effects of a Truncated Supply Shock on Oil Prices in the High B Oil Price Case**

## 6.5 ESTIMATING IMPACTS ON THE PRICE ELASTICITY OF U.S. OIL DEMAND

Prospective assessment of the impacts of DOE's energy efficiency R&D programs on the price elasticity of petroleum demand requires a method for deriving relationships between the technologies being researched and developed by DOE (e.g., advanced energy efficient vehicle technologies, biomass fuels for blending with gasoline and diesel fuel, hydrogen production and fuel cell vehicles, etc.) and the price elasticity of U.S. demand for petroleum. A method is

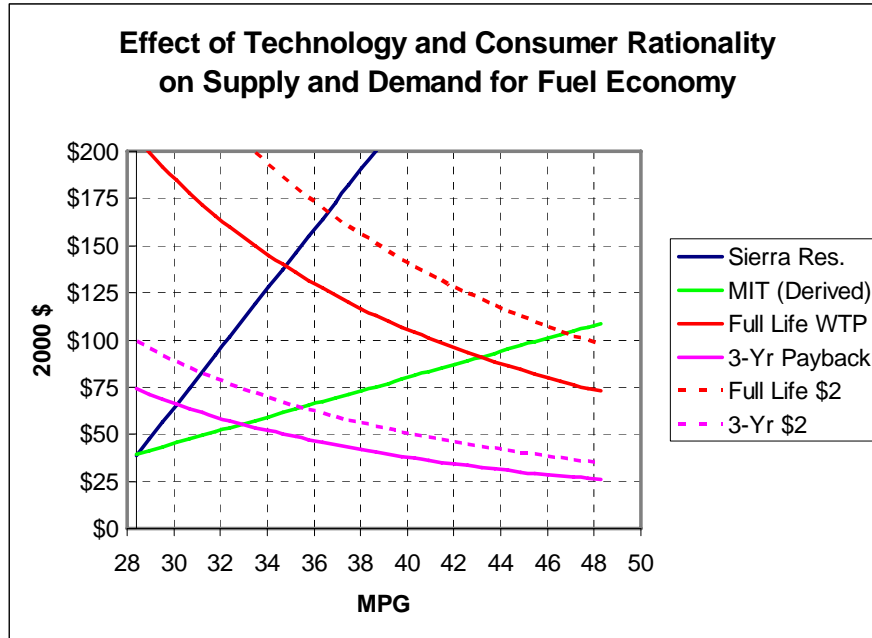
presented below that uses information on the costs of fuel economy improving technologies to derive the price elasticity of new vehicle fuel economy, which is a major component of the price elasticity of gasoline demand. The method is based on Greene's (1997) methodology for translating changes in the costs and fuel economy impacts of specific technologies into changes in, (1) the supply curve for fuel economy, (2) the price elasticity of demand for gasoline, and (3) the price elasticity of U.S. demand for petroleum. Schock et al. (1999) developed a framework for estimating the energy security benefits of energy R&D using such information. Greene (1997) also outlined an approach for calculating the impacts of alternative fuel use on the price elasticity of U.S. demand for petroleum, and this is formalized below to capture the effects of EERE's alternative fuels R&D programs.

The potential impact of advanced technologies on the cost of increasing passenger car fuel economy can be seen in the fuel economy cost curves published in the NRC's (2002) report on fuel economy standards in the United States (Figure 25). All the curves represent proven technologies except those labeled "2020 MIT" and "ACEEE-Advanced," which anticipate significant future technological progress. Clearly, the advanced technology curves allow much greater levels of fuel economy to be achieved at lower cost. The curve labeled "Sierra Research" and the "2020 MIT" curve can be used to illustrate the impact advanced technology can have on vehicle fuel economy.



**Figure 25. Comparison of Current and Advanced Technology Fuel Economy Cost Curve**

Marginal cost curves (which are fuel economy supply curves) derived from the Sierra (1999) and MIT total cost curves are shown in Figure 26. On the same graph are plotted fuel economy demand curves, representing the marginal, present value to consumers of increased fuel economy under different assumptions about the price of gasoline (\$1.50 v. \$2.00/gallon) and the period of time over which consumers "count" the value of fuel saved (the first 3 years, versus the expected 14-year life of a light-duty vehicle in the United States).



**Figure 26. Effect of Advanced Fuel Economy Technologies and Consumer Behavior on the Market Response of Fuel Economy to an Increase in the Price of Gasoline**

The gasoline price elasticity of fuel economy is the ratio of the percent change in fuel economy to the percent change in gasoline price (from \$1.50 to \$2.00). Elasticities calculated using the 3-year payback curves are shown in Table 2 (the midpoint formula is used in estimating elasticities). Given the current technology curve, the \$0.50 increase in the price of a gallon of gasoline produces a 1.1 increase in new car MPG, implying a price elasticity of +0.13. Given the same assumptions the advanced technology curve produces a 2.4 MPG gain, for an elasticity of +0.25, almost twice the current technology elasticity number. It remains to calculate the impact of this change on the price elasticity of gasoline demand. In the analysis of security benefits of advanced hybrid vehicle technology presented in Chapter 8, elasticities are calculated over a price range from \$2 to \$3 per gallon.

**Table 2. Potential Impact of Advanced Technology on the Fuel Price Elasticity<sup>†</sup> of Passenger Car Fuel Economy (Greene, 2005)**

Source of Technology Estimates	MPG at \$1.50/gal.	MPG at \$2/gal.	Gasoline Price Elasticity of MPG	% Change
Sierra Research Current Tech.	30.1	31.2	0.13	--
MIT 2020 Technology	33.0	35.4	0.25	+92%

<sup>†</sup>Based on undiscounted fuel savings over the first three years of vehicle life. Assumes an initial average fuel economy of 28.0 miles per gallon.

### 6.5.1 Price Elasticities of Motor Fuel and Fuel Economy

The fuel price elasticity of fuel economy affects the price elasticity of motor fuel demand which in turn impacts the price elasticity of petroleum demand. Fuel demand (f) by motor vehicles is equal to the demand for travel (m) divided by fuel economy (e) in miles per gallon ( $f = m/e$ ). This simple identity implies that the price elasticity of fuel demand ( $\beta_{f,p} < 0$ ) is the following function of the price elasticity of fuel economy ( $\beta_{e,p} > 0$ ) and the elasticity of travel with respect to fuel cost per mile ( $\beta_{m,c}$ ).

$$\beta_{f,p} = [\beta_{m,c} (1 - \beta_{e,p})] - \beta_{e,p} \quad (28)$$

The elasticity of fuel economy with respect to price can be decomposed into two parts, one representing the effect of technology, the other of changes in the mix of vehicle sold. Advances in technology directly affect only the technology portion. Recent analyses of financial incentives to increase vehicle fuel economy indicate that in the long run about 90% to 95% of the fuel economy response is due to the use of technology and only 5% to 10% is due to consumers buying smaller or less powerful vehicles (see, e.g., Greene, Hopson and Li, 2005 for a review).

Finally, a change in vehicle technology will have a smaller impact on the price elasticity of demand for petroleum than it has on the price elasticity of demand for motor fuel for two reasons. First, the cost of petroleum is only a part of the cost of fuel. In the United States, taxes, refining, distribution, and marketing costs, plus profits, normally amount to about \$0.80/gallon (U.S. DOE/EIA, 2001). At \$21/bbl, the cost of crude oil would be \$0.50/gallon, while at \$63/bbl crude oil would comprise \$1.50 of the price of gasoline. Assuming that crude oil costs comprise \$0.80/gallon, the effect of vehicle technology on the price elasticity of crude oil would be exactly half of its effect on the price elasticity of motor fuel.

$$\beta_{o,p} = \beta_{f,p} \frac{dP_f}{dP_o} = 0.5\beta_{f,p} \quad (29)$$

Typical values for these elasticities in the United States are,  $\beta_{m,c} = -0.1$ ,  $\beta_{e,p} = 0.15$ , which imply that  $\beta_{f,p} = -0.24$ . If advanced technologies could increase  $\beta_{e,p}$  from 0.15 to 0.3, then the price elasticity of fuel demand would increase to -0.37, a increase in elasticity of 57%. Automobiles and light trucks account for 61% of U.S. transportation energy use; highway vehicles in total account for 81% (Davis and Diegel, 2004, table 2.5). Because 66% of the petroleum consumed in the United States and nearly all the high-value products go to transportation, highway vehicles are responsible for 54% of U.S. total petroleum consumption. Thus, a 57% increase in the price elasticity of demand for highway motor fuel could raise the overall elasticity of U.S. petroleum demand by 30%. A thirty percent increase in the price elasticity of U.S. petroleum demand could yield significant energy security benefits by reducing the price shock associated with a given size of supply disruption and by reducing the negative impacts on the U.S. economy of a given price shock.



### 6.5.2 Advances in Vehicle Technology and the Price Elasticity of Fuel Economy

This section presents equations that can be used to estimate the impacts of advanced technologies on the price elasticity of petroleum demand. The method below is presented using passenger cars as an example, but it can be generalized to other technologies that reduce the cost of increasing energy efficiency. In the case of energy efficient vehicle technology, technological change can be described by a functional relationship between increased vehicle cost and increased fuel economy. Such curves have been used by the NRC (1992; 2002) and others to describe the status of fuel economy technology.<sup>18</sup> With cumulative cost on the vertical axis and cumulative fuel economy improvement on the horizontal axis, technological progress consists of a rightward shift in the curve (see, e.g. Figure 9).

Estimates of the cumulative cost of fuel economy improvements due to the application of technology and design changes can be accurately described by a quadratic function of the relative change in miles per gallon (Greene and DeCicco, 2000; Plotkin, Greene and Duleep, 2002, ch. 6). When the total cost curve is quadratic it follows that the marginal cost (MC) or supply curve is linear in  $\varepsilon$ .

$$C = b\varepsilon + c\varepsilon^2 \quad , \quad MC = \frac{dC}{d\varepsilon} = b + 2c\varepsilon \quad (30)$$

In equation 30,  $C$  is total incremental retail price increase,  $\varepsilon$  is the relative change in miles per gallon  $(MPG - MPG_0)/MPG_0$ ,  $MC$  is the marginal cost or supply curve for fuel economy and  $a$ ,  $b$ , and  $c$  are empirical coefficients.

The first step is to estimate two total cost curves for fuel economy improvement, one without and one with EERE advanced technologies. Several studies have developed quadratic fuel economy cost curves for conventional, gasoline internal combustion engine vehicles (e.g., Greene and DeCicco, 2000; NRC, 2002; Greene, Hopson and Li, 2005). Curves for EERE technologies can be estimated with data on two technologies (data for only one technology would produce a linear total cost curve and a constant marginal cost which would still allow an elasticity to be calculated). A quadratic curve passing through the origin is determined by two additional points. Given the cost and fuel economy improvement potential of two EERE technologies,  $(C_1, \varepsilon_1)$ ,  $(C_2, \varepsilon_2)$ , such that  $C_1/\varepsilon_1 < C_2/\varepsilon_2$ , the two points on the cumulative cost curve are  $(C_1, \varepsilon_1)$  and  $(C_1 + C_2, \varepsilon_1 + \varepsilon_2)$ . The parameters of the curve are given by the following equations.

$$c = \left( C_1 - \frac{(C_1 + C_2)\varepsilon_1}{(\varepsilon_1 + \varepsilon_2)} \right) \div (\varepsilon_1^2 - \varepsilon_1(\varepsilon_1 + \varepsilon_2))$$

$$b = \frac{C_1 + C_2}{\varepsilon_1 + \varepsilon_2} - c(\varepsilon_1 + \varepsilon_2) \quad (31)$$

<sup>18</sup> The NRC (2002) fuel economy study also represented fuel economy technology in terms of cost per gallon per mile of fuel reduction.

The next step is to derive a demand curve for increased fuel economy. The total value to the consumer of increased fuel economy can be expressed as the discounted present value of future fuel savings. Let  $P$  be the price of fuel,  $E$  the initial vehicle fuel economy,  $M$  the miles a vehicle travels when new,  $\delta$  be the rate of decline in vehicle use with age (time),  $r$  be the consumers discount rate,  $L$  the expected vehicle life (or alternatively the period of time over which the car buyer is believed to consider the value of fuel savings), and  $t$  represent time. The present value (therefore comparable to retail price) of an increase in fuel economy from  $E$  to  $E(1+\varepsilon)$ , is given by the following integral.

$$V = \int_0^L PM \left( \frac{1}{E} - \frac{1}{E(1+\varepsilon)} \right) e^{-(r+\delta)t} dt = \frac{PM}{r+\delta} \left[ 1 - e^{-(r+\delta)L} \right] \left( \frac{1}{E} - \frac{1}{E(1+\varepsilon)} \right) \quad (32)$$

Holding  $r$ ,  $\delta$ ,  $L$  and  $M$  constant and representing the terms involving them by  $K$ , gives the following simpler formula in terms of the price of fuel,  $P$ , base fuel economy  $E$ , and relative increase in fuel economy,  $\varepsilon$ .

$$V = \frac{KP}{E} - \frac{KP}{E(1+\varepsilon)} \quad , \quad MV = \frac{dV}{d(E(1+\varepsilon))} = \frac{KP}{(E(1+\varepsilon))^2} \quad (33)$$

The competitive market solution to this problem occurs where  $MC=MV$ , which is the point at which the net value to the consumer (fuel savings – price increase) is maximized. The points at which the marginal cost ( $MC$ ) and marginal value ( $MV$ ) curves intersect is found using the Excel Solver software. The solution space for  $MC=MV$  and  $E(1+\varepsilon)$  is restricted to the positive quadrant ( $E(1+\varepsilon) > 0$ ,  $MC > 0$  and  $MV > 0$ ). Given this constraint, the deviation between  $MC$  and  $MV$  is minimized. Solutions are found for each curve at two different price levels in the vicinity of the EIA forecast in question, e.g., \$2/gal. and \$3/gal. The price elasticity of fuel economy is then calculated using the midpoint formula.

$$\beta_{E,P} = \frac{\varepsilon^*(P_1) - \varepsilon^*(P_2)}{P_1 - P_2} \frac{(P_1 + P_2)}{\varepsilon^*(P_1) + \varepsilon^*(P_2)} \quad (34)$$

This elasticity is calculated for both the baseline total cost curve and the advanced technology total cost curve.

### 6.5.3 Effect of Alternative Fuels and Non-Petroleum Blends on the Price Elasticity of Petroleum Fuel Demand

This section demonstrates how increases in the market shares of alternative fuels and replacement fuels, and in their costs, affect the price elasticity of demand for petroleum fuels, such as gasoline and diesel.

Let “gasoline” represent petroleum transportation fuels, in general. Gasoline demand,  $G$ , is identically equal to the total demand for motor fuels,  $F$ , times gasoline’s share of total motor fuel demand,  $s_g$ .

$$G = F s_g \quad , \quad s_g = \frac{G}{F} \quad (35)$$

The price elasticity of demand for gasoline,  $\beta_g$ , can be shown to be a function of the price elasticity of demand for all motor fuel,  $\beta_f$ , the expenditures on gasoline relative to all motor fuels,  $\omega_g$ , and the price elasticity of gasoline's market share  $\gamma_g$ .

$$\begin{aligned} \frac{dG}{dP_g} &= \frac{dF}{dP_g} s_g + F \frac{ds_g}{dP_g} \\ \beta_g &= \frac{dG}{dP_g} \frac{P_g}{G} = \frac{dF}{dP} \frac{dP}{dP_g} \frac{P_g}{G} \frac{P}{P} \frac{G}{F} + \frac{ds_g}{dP_g} \frac{P_g F}{G} \\ &= \left( \frac{dF}{dP} \frac{P}{F} \right) \frac{G}{F} \frac{P_g}{P} + \frac{ds_g}{dP_g} \frac{P_g}{s_g} \\ &= \beta_f \omega_g + \gamma_g \end{aligned} \quad (36)$$

If a multinomial logit model is assumed as a functional form for the choice of motor fuel, then the elasticity of market share is the following function of the price of gasoline, gasoline's market share, and the coefficient of price in the logit model,  $b_g$ . The share of non-petroleum fuels is represented by  $s_r$ .

$$\gamma_g = (1 - s_g) b_g P_g = s_r b_g P_g \quad (37)$$

Substituting this result into the equation for the price elasticity of demand for gasoline shows that the elasticity is an increasing function of the market share of alternative and replacement fuels,  $s_r$ . Let  $R$  be the demand for replacement fuels.

$$\beta_g = \beta_f \frac{G}{F} \frac{P_g}{P} + s_r b_g P_g = \beta_f s_g \frac{P_g}{P} + s_r b_g P_g = \frac{\beta_f}{1 + \frac{RP_r}{GP_g}} + s_r b_g P_g \quad (38)$$

Note that the first term on the right-hand side approaches  $\beta_f$  as  $R \rightarrow 0$  and approaches 0 as  $R \rightarrow F$ .



## 7. NON-MONETARY METRICS OF OIL SECURITY BENEFITS

Some potential oil security benefits cannot be adequately measured in monetary terms by the methods embodied in the OSMM. The two major categories of non-monetary oil security benefits are contingency costs, or insurance costs that are primarily incurred during “normal” energy market conditions in order to insure against possible future supply disruptions, and military, strategic and foreign policy costs.<sup>19</sup> Until consensus methodologies can be developed for monetizing these types of oil security benefits, non-monetary metrics can be used to describe the prospective benefits of DOE’s R&D programs.

Table 3 lists four non-monetary metrics recommended by Lee (2005, table 8) and fifteen related metrics that are outputs of the Oil Security Metrics Model. Of the four metrics recommended by Lee, three are directly available from the metrics model; only the price elasticity of fuel supply is currently not produced by the model. One monetary metric can be calculated: the SPR cost savings assuming a constant size in days of import replacement.

**Table 3. Non-Monetary Metrics of U.S. Oil Security**

<b>Energy Security Metrics Recommended by Lee (2005)</b>	
1	U.S. Oil Imports as a percentage of consumption
2	Domestic oil consumption
3	Estimate of price elasticity of U.S. fuel supply
4	Estimate of price elasticity of U.S. oil demand
<b>Metrics Produced by the Oil Security Metrics Model</b>	
1	<b>U.S. Oil Consumption</b>
2	U.S. Oil Consumption per Dollar of GDP
3	U.S. Oil Imports
4	<b>Imports as a Share of U.S. Oil Consumption</b>
5	U.S. Wealth Transfer
6	U.S. Oil Expenditures
7	U.S. Oil Expenditures as a Share of GDP
8	SPR Size at Constant Days of Import Replacement
9	SPR Days of Import Replacement at Constant Size
10	<i>SPR Cost Savings Assuming Constant Days of Import Replacement</i>
11	<b>Estimated U.S. Price Elasticity of Oil Demand</b>
12	World Oil Price
13	OPEC Share of World Oil Market
14	OPEC Gross Revenues from Oil Sales
15	Oil Dependence Costs Relative to U.S. GDP

Due to uncertainty about OPEC’s response to changes in U.S. oil demand, outputs from the oil market simulation model will allow only a bounding of world dependence on imports from

<sup>19</sup> As the term is used here, non-monetary implies that the benefits are not measured in present value dollars, although the indicator itself may be in units of dollars (e.g., the price of oil or total OPEC revenues).

OPEC. Neither world dependence on the Persian Gulf nor U.S. dependence on OPEC or Persian Gulf imports is an output of the model, due to the simplicity of the world oil market model (Figure 27).

The historical data indicate that during the decade from 1970-1980, OPEC's share of the world oil market was at its peak, near 50% (Figure 28). At the same time, the costs of oil dependence to the United States were at their highest levels (see Figure 9). World oil prices were also at their highest levels during this period (Figure 29). Prices have recently risen again to near historic highs, despite OPEC's market share remaining in the vicinity of 40%.

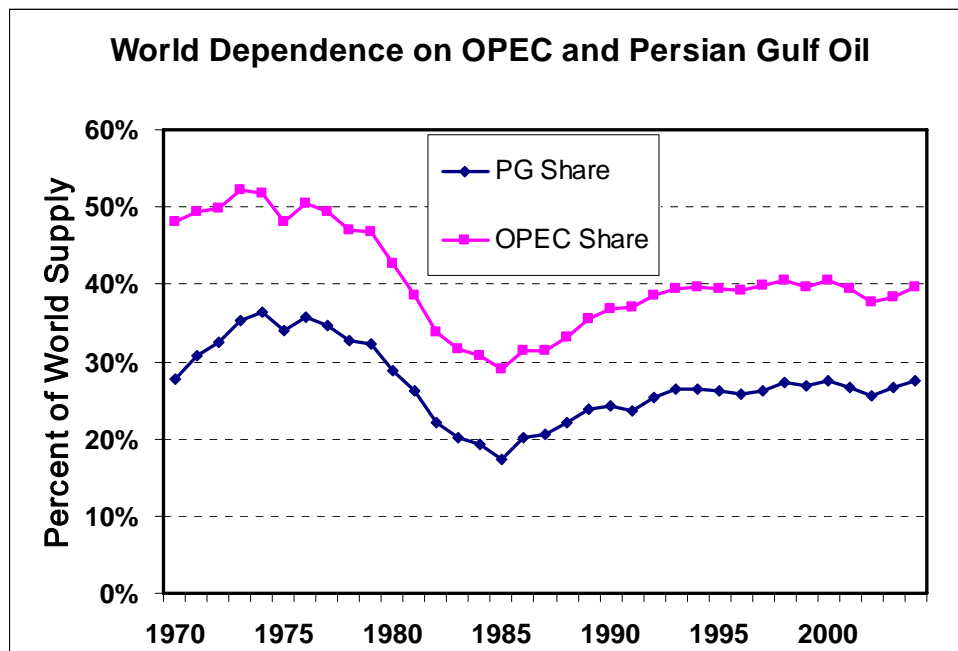


Figure 27. World Dependence on OPEC and Persian Gulf Oil

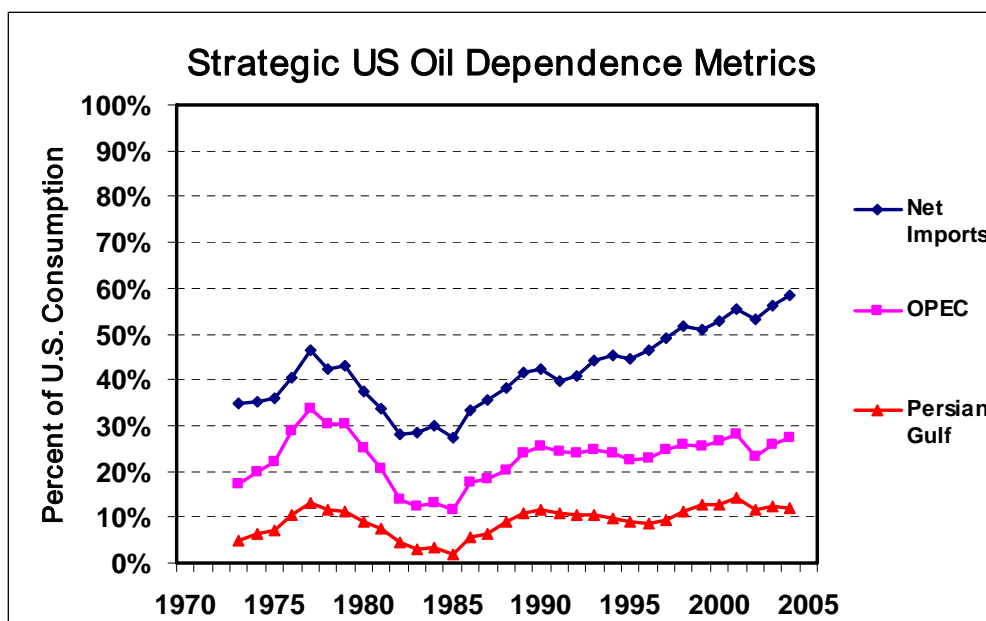
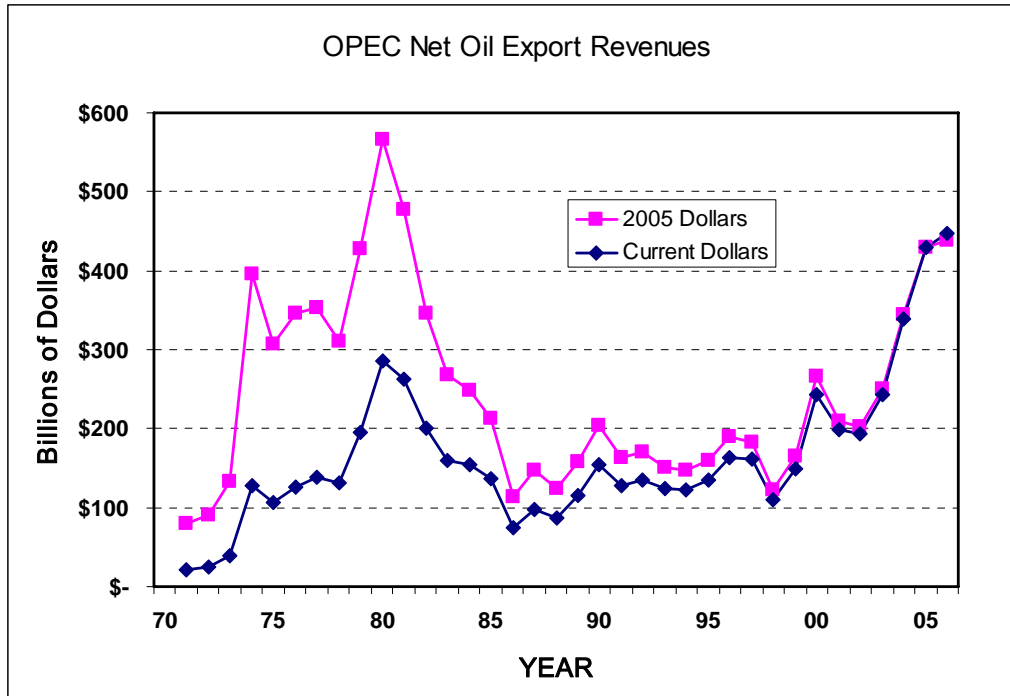


Figure 28. U.S. Dependence on Imports from OPEC and the Persian Gulf

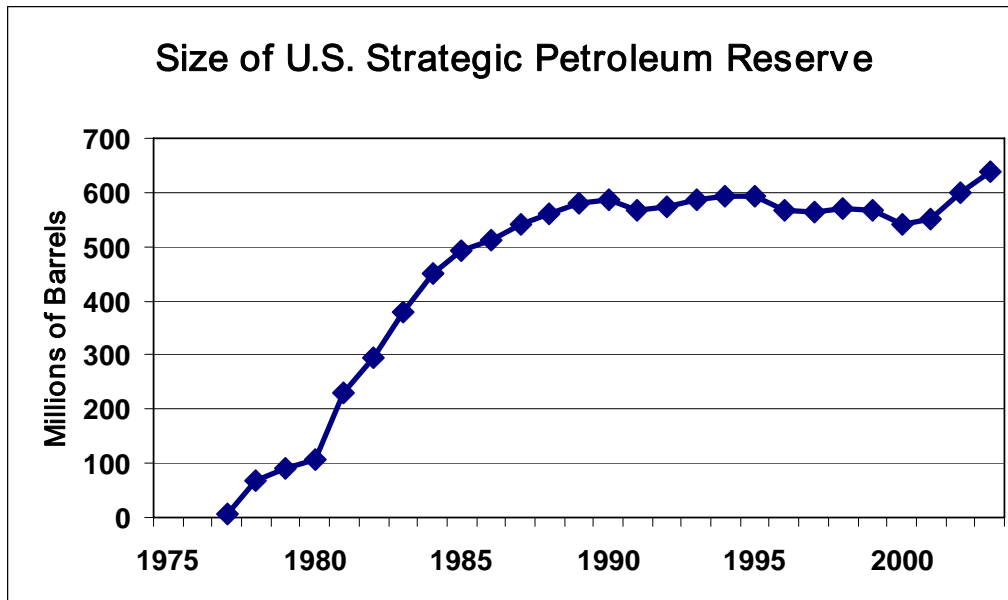


**Figure 29. OPEC Revenues from Net Oil Exports**

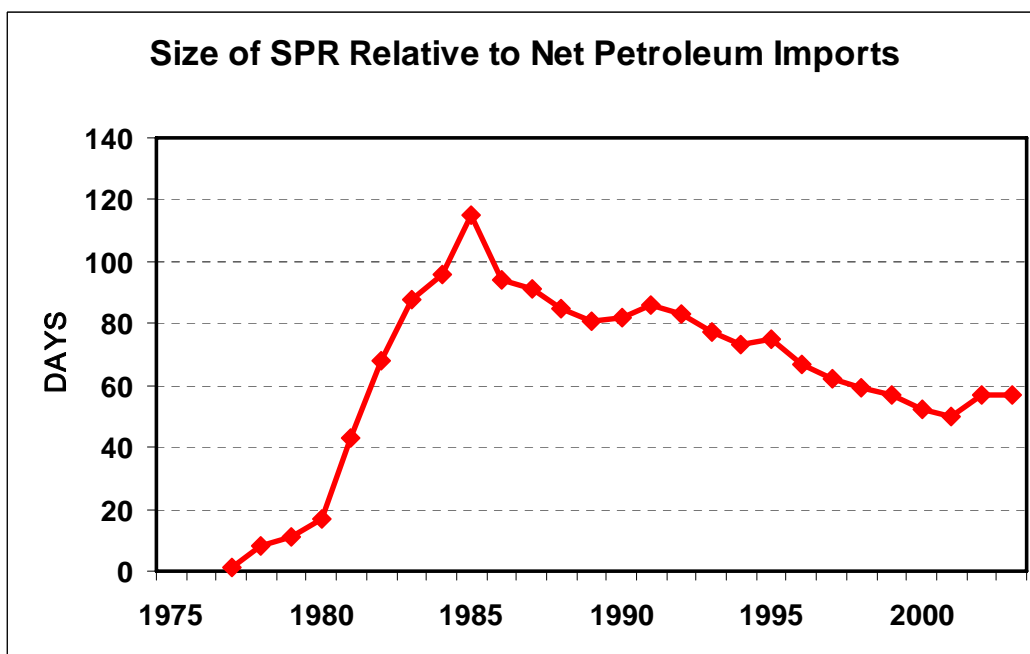
The change in OPEC revenues as a result of the impacts of advanced technology can also be bounded by the methods described above. The bounds are likely to be narrow and OPEC revenues will decrease, in any case. Either OPEC will maintain production, in which case the price of oil will fall decreasing its revenue, or it will maintain the price of oil, in which case it must cut production. In either event, OPEC revenues will decrease. Historically, OPEC revenues have closely tracked world oil prices.

The impacts of reduced U.S. oil demand on the SPR cannot be predicted because the size and management of the SPR are determined by government policy. Yet, plausible bounding cases can be defined. If SPR reserves are maintained at the same size despite a decrease in U.S. petroleum use (or imports), then the amount of insurance provided by the SPR, as measured by the size of the reserve relative to imports, increases. At present, there is no method for attaching a monetary value to such an increase, although one could be derived from the work of Leiby and Bowman (2000) on optimal SPR sizing. If the days of reserves (SPR size in barrels divided by imports in barrels per day) are assumed to be maintained, then SPR stocks and the costs of holding those stocks will decrease. This will result in direct cost savings which are calculated as metric 10. These two measures, (1) the increase in days of reserves, or (2) savings on maintaining the SPR, are useful metrics of oil security impacts.

Historically, the size of the SPR was increased steadily up to 600 billion barrels and then held approximately constant (Figure 30). The insurance value in days of imports, however, peaked in 1985 and has since decreased as U.S. imports have increased (Figure 31).



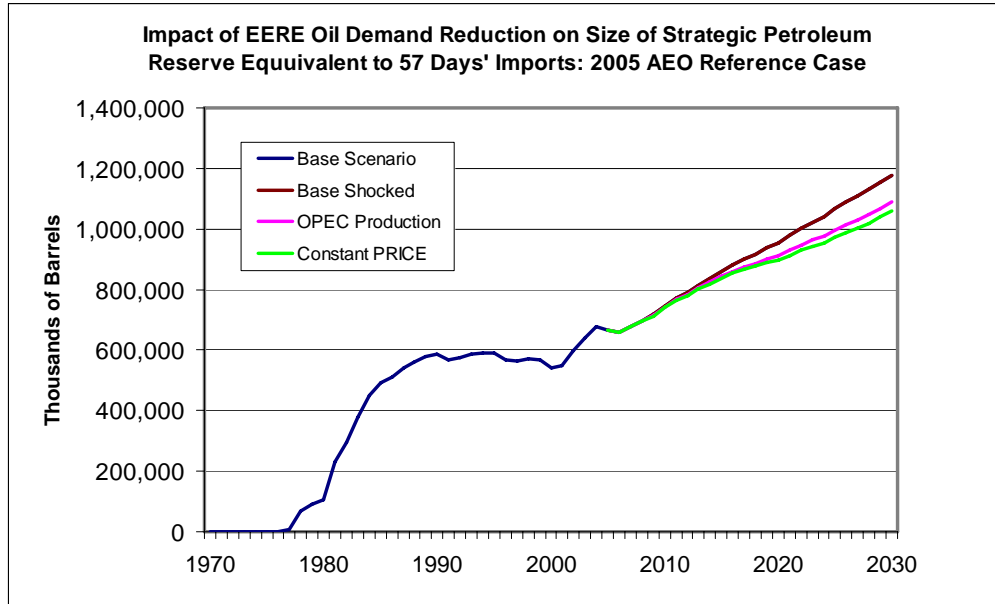
**Figure 30. Size of the U.S. Strategic Petroleum Reserve (SPR)**



**Figure 31. Size of the U.S. Strategic Petroleum Reserve (SPR) Relative to Net Imports**

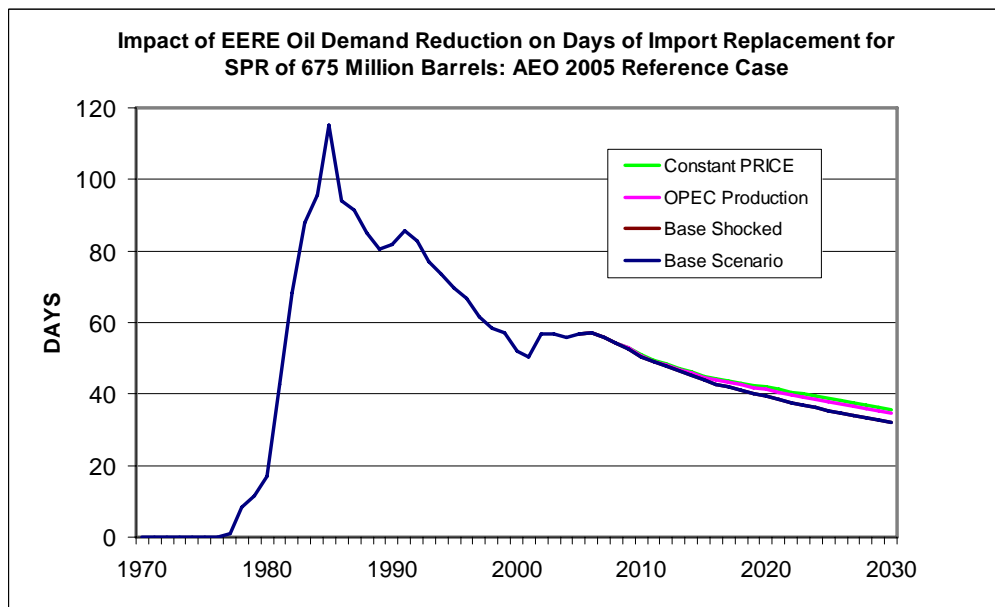
Impacts of DOE's R&D programs on the SPR are described by two non-monetary metrics and one measure of dollar savings. The non-monetary metrics are: (1) the size of reserve required to replace 57 days of imports (the 2004 level of import replacement provided by the SPR, Figure 32), and (2) the number of days of import replacement provided by an SPR of 675 million barrels of petroleum (the current size of the reserve) (U.S. DOE/EIA, 2005, table 5.17).





**Figure 32. Size of SPR to Replace 57 Days of Oil Imports: Reference Scenario**

The stocks needed to replace 57 days of imports in the Reference Case increases from 675 million to 1,176 million barrels by 2030. As an illustration, the estimated impacts of DOE's hybrid vehicle technology R&D on oil demand would result in 87 million fewer barrels needed to provide the same level of replacement assuming OPEC holds to the Reference Case production schedule, and 115 million fewer barrels if OPEC maintains the prices of the Reference Case in the face of reduced U.S. demand.



**Figure 33. Days of Import Replacement Provided by an SPR of 657 Million Barrels: Reference Case**

If the SPR is held at its 2004 size of 675 million barrels, the days of import replacement it affords in the AEO 2005 Reference Case decline quickly as U.S. imports increase. Oil saved by hybrids is estimated to add three days to the import replacement capability of a 675 million

barrel SPR if OPEC does not change its production and 4 days if OPEC maintains the oil price path of the Reference Case.

The dollar value of these marginal changes in U.S. oil demand can be approximated by calculating the change in total SPR costs assuming that 57 days of import replacement is maintained. Total costs are comprised of: (1) capital, operating and maintenance costs including withdrawal (Leiby and Bowman, 2000, indicate that these are roughly \$5/bbl), (2) oil purchase costs, and (3) opportunity costs of holding oil in reserve. Oil is assumed to be purchased in the year it is required to maintain the 57 day coverage and is valued at the oil price for that year. Opportunity costs equal the value of the oil in storage at current year prices, times the discount rate (the default rate is 3%/year). Future costs are converted to present value by the same discount rate. For the Reference Case projections shown in Figures 19 and 20, the present value savings are \$1.7 billion in the OPEC maintains production case and \$2.2 billion in the OPEC maintains price case.

## 8. ADVANCED HYBRID VEHICLES: A TEST CASE

The Oil Security Metrics Model was used to estimate the prospective oil security benefits of advanced hybrid vehicle technology to illustrate the application of the model and the kinds of results it produces. As explained in Chapter 6, the OSMM does not estimate technological success, market success or the impacts of DOE's technology R&D on U.S. oil consumption. It estimates oil security benefits as a result of given reductions in U.S. oil consumption and changes in the cost and performance of energy efficient technologies and alternative fuels that affect the price elasticity of oil demand.

For this illustration, VISION Model estimates of the impacts of advanced hybrids on U.S. oil consumption were provided by Singh (2006). Estimates of the cost (retail price equivalent) and fuel economy improvement potential of advanced hybrid technology were obtained from Das (2005). Four scenarios of future oil market conditions were taken from the 2006 Annual Energy Outlook (U.S. DOE/EIA, 2006). The four AEO projections span a wide range of oil prices from \$28/bbl to \$90/bbl in 2030 Table 4). OPEC production ranges from 31.7 million barrels per day (mmbd) in the High Price projection to 50.8 mmbd in the Low Price case. U.S. oil consumptions are lowest in the High Price case at 25.2 mmbd in 2030 and highest in the High Growth case at 30.6 mmbd in 2030. World oil demand varies from 101.9 mmbd in the High Price case up to 127.7 mmbd in the Low Price projection.

**Table 4. Key Oil Market Variables from Four AEO 2006 Projections**

		Reference		High Price		Low Price		High Growth	
	2005	2015	2030	2015	2030	2015	2030	2015	2030
World Oil Price (\$/bbl)	\$49.70	\$43	\$50	\$72	\$90	\$29	\$28	\$43	\$50
OPEC Supply (mmbd)	32.15	38.3	45.8	28.9	31.7	40.6	50.8	38.3	45.8
US Demand (mmbd)	21.14	23.6	27.6	22.2	25.2	24.5	29.7	24.8	30.6
World Demand (mmbd)	87.18	96.9	117.8	90.6	101.9	101.4	127.7	96.9	117.8

Data entry to set up a model run is accomplished in three steps. First, the estimated reductions in U.S. oil consumption produced by the VISION Model are entered into the spreadsheet. The spreadsheet converts reductions measured in barrels per day to percent reductions from the AEO 2006 Reference Case projection of U.S. oil consumption. Conversion to percentages allows the reductions to be applied to the three other projection scenarios. Second, the costs and fuel economy increases for two advanced hybrid technologies are entered in the Elasticity spreadsheet. In the Elasticity spreadsheet the Excel Solver is used to calculate (1) the change in the price elasticity of fuel economy, (2) the consequent change in the price elasticity of light-duty vehicle motor fuel demand and, finally, (3) the change in the price elasticity of U.S. oil demand. Data entry is completed by setting key parameter values in the Parameters worksheet.

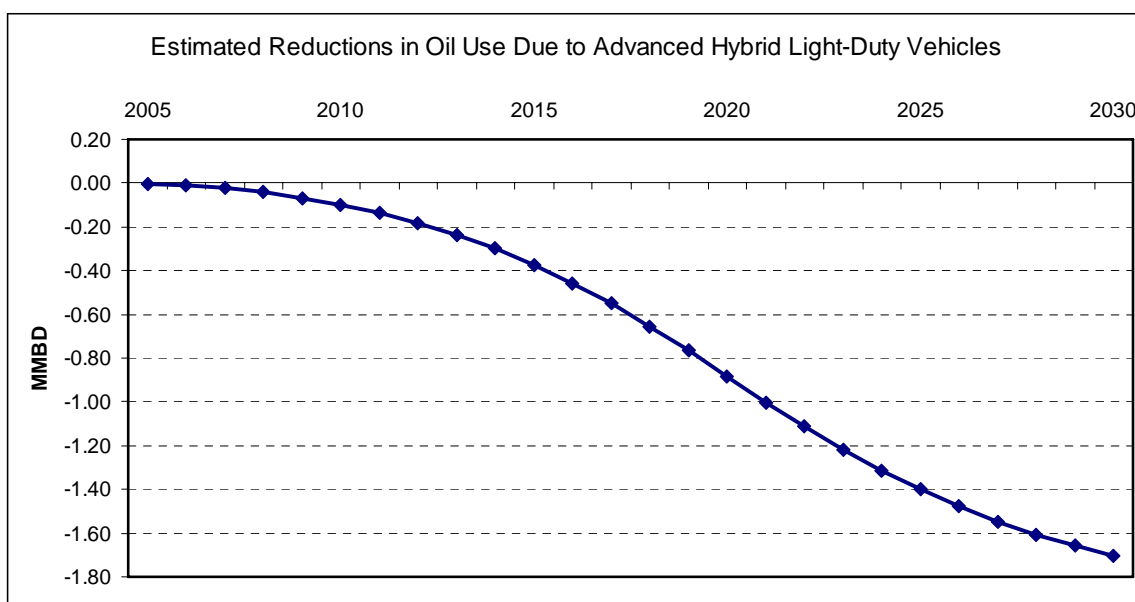
Calculating oil security net benefits requires two full simulation runs of the OSMM because the oil security net benefits are the difference between the benefits of DOE's R&D programs under "normal," undisrupted, market conditions and the benefits under disrupted market conditions. Undisrupted market conditions are simulated by turning off a switch in the Parameters worksheet that toggles the stochastic supply disruption model. A set of 1,000 simulations is then run without supply disruptions disturbing the AEO projections. For each individual simulation the model randomly selects one of the four AEO projections and randomly selects parameter values

for those parameters that are specified as probability distributions. The @Risk simulation software keeps track of four different estimates of gross benefits:

5. Benefits calculated using method 1 and assuming OPEC maintains its original AEO projection oil production schedule,
6. Benefits calculated using method 1 and assuming OPEC reduces output to maintain the original AEO projection's price path,
7. Benefits calculated using method 2 and assuming OPEC maintains its original AEO projection oil production schedule,
8. Benefits calculated using method 2 and assuming OPEC reduces output to maintain the original AEO projection's price path.

A second set of 1,000 simulations is then run with the supply disruption model turned on. The same four measures of gross benefits are recorded. The expected oil security net benefits of advanced hybrid vehicle technology is equal to the mean benefits obtained in the presence of supply shocks minus the mean benefits obtained from the simulations without price supply shocks.

The reductions in U.S. oil consumption achieved by advanced hybrid vehicles were based on VISION Model impact estimates for the 2005 AEO Reference Case were provided by Singh (2006). The 2006 AEO Reference Case projects slightly lower 2025 energy use by light duty vehicles than the 2005 AEO: 22.4 quads versus 24.5 quads, respectively. In addition, the 2006 AEO includes a projection to 2030 while the 2005 AEO ends at 2025. The VISION model estimates for the 2005 AEO extrapolated to 2030 were converted to percent reductions in light-duty vehicle energy use, and these percentages were applied to the AEO 2006 projection to estimate the reductions shown in Figure 34 in millions of barrels per day. The reductions follow an s-shaped curve from no reduction in 2005 to reach -1.7 mmbd per year by 2030 (Figure 34).



**Figure 34. VISION Model Estimates of Reductions in Oil Use as a Result of Advanced Hybrid Technology for Light-Duty Vehicles**

In relative terms, advanced hybrid vehicle technologies reduce light-duty vehicle oil use by about 0.1% in 2006, increasing to a 10% reduction by 2022 and reaching a 14% reduction by 2030. This amounts to a 6.2% reduction in total U.S. petroleum consumption by 2030 in the AEO 2006 Reference Case.

The second step in setting up a model run requires estimating changes in the price elasticity of oil demand as a result of advances in energy efficient technology or the market penetration of alternative fuels. In this example, no change in alternative fuels demand results from the introduction of advanced hybrid technology. The entire effect comes via reducing the cost of increased vehicle fuel economy.

The advanced hybrid fuel economy technology cost curve is defined by two points and the assumption that it passes through the origin. The two points are the cost and relative fuel economy improvement potentials of advanced integrated starter-generator (ISG) technology and full hybrid technology. The cost and fuel economy improvement assumptions are shown in Table 5 and plotted in Figure 35. The ISG hybrid, which enables engine start-stop, as well as some regenerative braking and a moderate power boost from the electric motor during acceleration, is assumed to improve fuel economy by 24% and add \$250 to the price of a vehicle (Das, 2005). The full hybrid which has a much larger battery pack for energy storage and is capable of all-electric operation at low speeds, adds another 39% fuel economy gain at an incremental RPE of \$750.

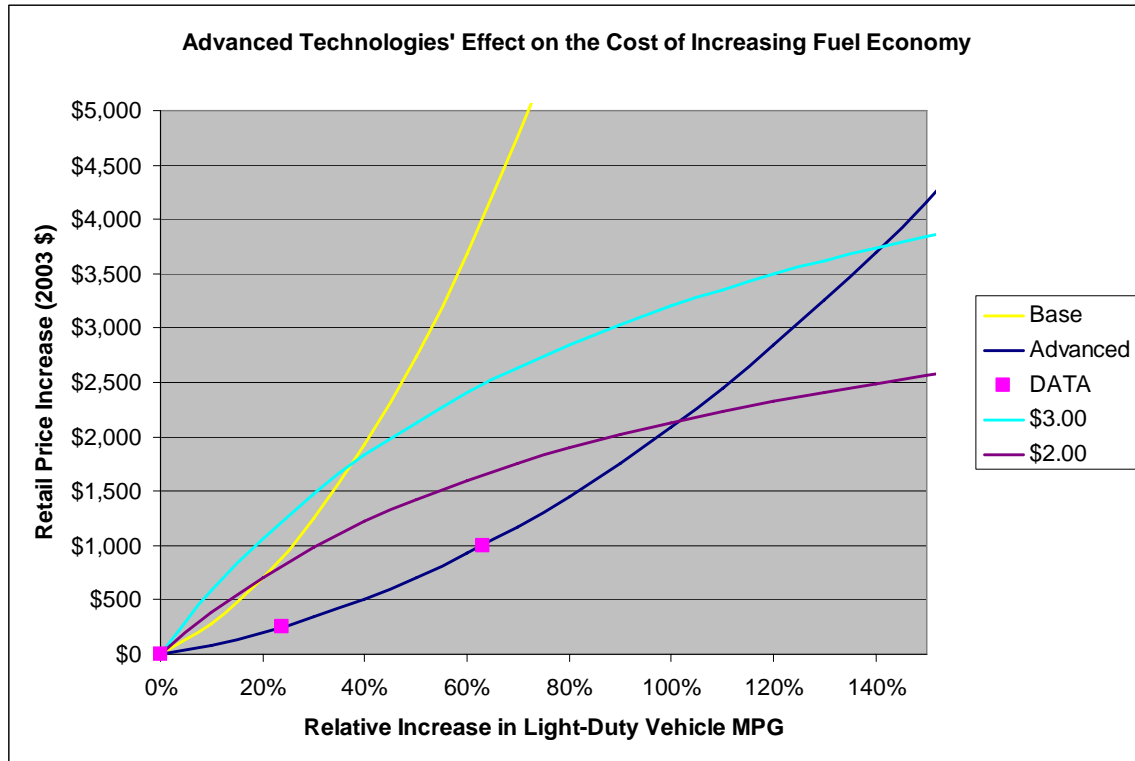
**Table 5. Fuel Economy Technology Cost Assumptions  
for Advanced Hybrid Technology**

Technology	Fuel Economy Gain	Cumulative F.E. Gain	Incremental Retail Price Equivalent	Cumulative RPE
ISG Hybrid	24%	24%	\$250	\$250
Full Hybrid	39%	63%	\$750	\$1,000

Source: Das, 2005

A quadratic cost curve fitted to the data shown in Table 5 is plotted in Figure 35, along with a “Base” technology cost curve derived from data in Austin et al. (1999) and cited in the National Research Council’s study of Corporate Average Fuel Economy standards (NRC, 2002). This cost curve was chosen for illustrative purposes because it implies relatively costly fuel economy improvements and is based on both existing and future technologies.

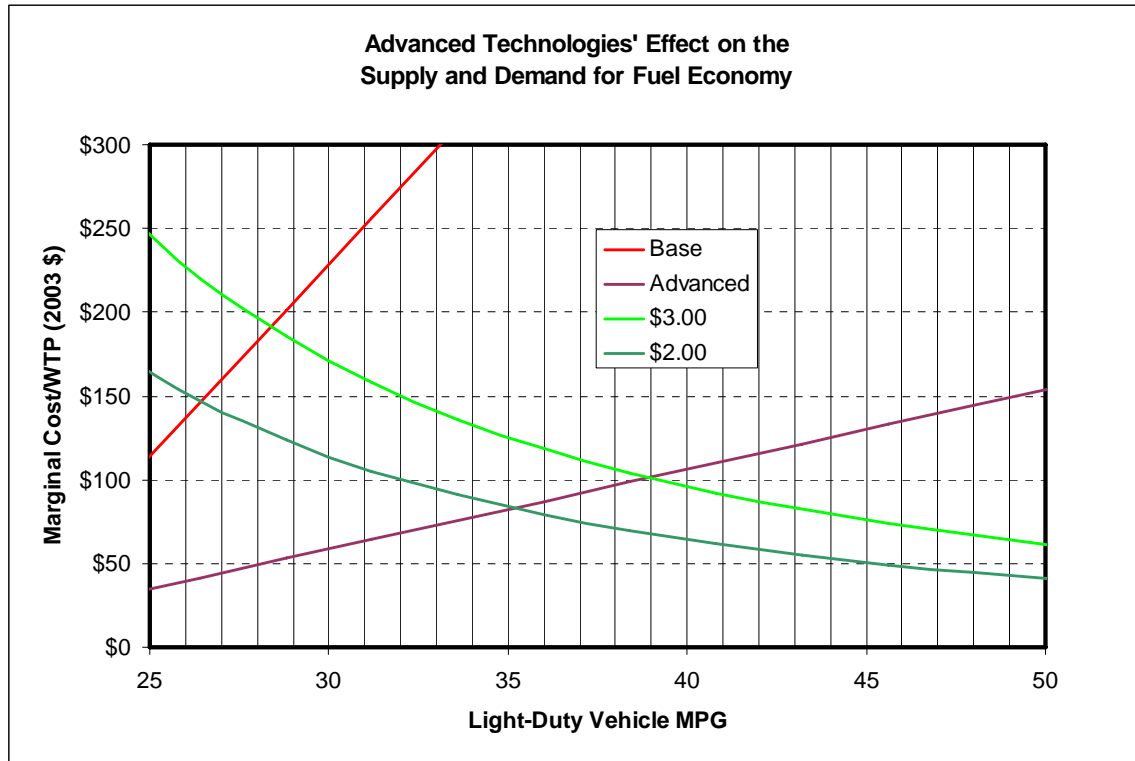
Curves describing the total value of fuel economy improvements to consumers are also plotted in Figure 35. These curves represent the present value of fuel savings to consumers based on the following assumptions: (1) a vehicle traveling 15,400 miles in its first year, decreasing at 4% per year, (2) savings counted over a 3-year vehicle life at 0% annual discount rate, and (3) assuming a base light-duty vehicle mpg of 24.0 and a 15% in-use MPG discount.



**Figure 35. Fuel Economy Technology Cost Curves for Advanced and Base Technology**

The derivatives of the total cost and total fuel savings curves are fuel economy supply and demand curves, respectively. Supply curves are plotted in Figure 36, along with two alternative demand functions based on gasoline at \$2 and \$3 per gallon. The intersections of supply and demand curves represent long-run market solutions for fuel economy at the respective price of gasoline.<sup>20</sup> These solutions are computed numerically in the OSMM model by invoking the Excel Solver. By comparing the effect on fuel economy of the change from \$2 to \$3/gallon to the relative change in price, arc price elasticities are calculated using the midpoint formula. These are assumed to be long-run price elasticities of fuel economy with respect to the price of motor fuel. Short-run elasticities are calculated by multiplying the long-run elasticities by an adjustment rate (the default is 0.15).

<sup>20</sup> The solution is a long-run market outcome because the fuel economy technologies can only be applied to new cars. Under normal conditions it would require 5-10 years to redesign all new cars and 15 years or more to turnover the fleet of vehicles on the road.



**Figure 36. Fuel Economy Technology Supply Curves for Base and Advanced Technology and Demand Curves at \$3 and \$2 per Gallon**

The change in the motor fuel price elasticity of fuel economy is translated into a new price elasticity of motor fuel demand which is in turn translated into a new price elasticity of total oil demand, using the equations presented above in section 7.1.1. The resulting calculations are summarized in Table 6, below. The fuel price elasticity of fuel economy increases by 46% from 0.177 to 0.258. The impact on the price elasticity of motor fuel demand by light-duty vehicles is attenuated because adopting fuel economy technologies in new vehicles is only one component of consumers' response to higher fuel prices. The other key components are the elasticity of vehicle travel with respect to fuel cost and the effect of vehicle type choice on fuel economy.

**Table 6. Impact of Advanced Fuel Economy Technology on the Price Elasticity of Oil Demand**

	Advanced Technology		Baseline Technology	
	\$3/gal.	\$2/gal.	\$3/gal.	\$2/gal.
MPG	39.0	35.1	28.4	26.4
Incremental RPE	\$101	\$83	\$51	\$42
Elasticity of MPG	0.258		0.177	
	Long-Run	Short-Run	Long-Run	Short-Run
Elasticity of LDV Fuel Demand	-0.468	-0.0753	-0.394	-0.0633
Elasticity of U.S. Oil Demand	-0.267	-0.0400	-0.251	-0.0377

As a result, the price elasticity of light-duty vehicle fuel demand increases by only 19%, from -.394 to -.468. The impact on the price elasticity of oil demand is further diminished because light-duty vehicles account for only about 45% of U.S. petroleum demand and because the cost of petroleum comprises only about half of the cost of motor fuel. In the end, the price elasticity of U.S. petroleum demand increases by only 6%, from -0.251 to -0.267.

The final data entry step is to enter data for key parameters specifying the price elasticities of world oil supply and demand and adjustment rates, sensitivities of the economy to oil price shocks, the assumed competitive or non-cartelized market price of oil, parameters of the stochastic oil supply disruption model, and probabilities for each of the four AEO 2006 projections. The default values (used in the advanced hybrid analysis) for these parameters are shown in Table 7.

**Table 7. Key Parameters for Oil Security Metrics Model Simulations**

<b>Oil Price Disruption Costs</b>	<b>Distribution</b>	<b>Parameters</b>
Combined Oil Price Elasticity of GDP in 1983-86	Triangular	-0.09,-0.055,-0.02
Disruption Costs Share of Elasticity	Triangular	60%,75%,90%
Ratio of 1 <sup>st</sup> to 2 <sup>nd</sup> Year Disruption Costs	Triangular	1/3, 1/2, 1/3
Disruption Costs Adjustment Rate	Triangular	0.222,0.333,0.444
Constant (0) or Oil-Share (1) Elasticity	NA	1
Threshold Price Increase for Disruption Cost	NA	5%
<b>Potential GDP Losses</b>		
Potential GDP loss adjustment rate -- US Demand	NA	0.15
Potential GDP loss adjustment rate -- US Supply	NA	0.15
U.S. Oil Demand Elasticity	Triangular	-0.0577,-0.0377,-0.0177
U.S. Oil Supply Elasticity	Triangular	0.03,0.05,0.07
Constant (0) or Oil-Share (1) Dependent Multiplier	NA	1
Potential GDP Loss Multiplier	NA	1.5
Discount Rate (%/yr) =	3.0%	
<b>World Oil Market</b>		
R.O.W. Oil Demand Adj. Rate	NA	0.15
R.O.W. Oil Supply Adj. Rate	NA	0.15
R.O.W. Oil Demand Elasticity	Triangular	-0.07,-0.05,-0.03
R.O.W. Oil Supply Elasticity	Triangular	0.02,0.04,0.06
Curtail Supply Shock if OPEC Share <	NA	25%
<b>Competitive Oil Price</b>		
Mean Competitive Oil Price (2204 \$/bbl)	Triangular	\$12,\$13,\$14
Oil Price Drift (\$/yr) 2005-2030	Triangular	-\$0.10,\$0.00,\$0.10
Random Price Correlation	Triangular	0.1,0.2,0.3
<b>Oil Supply Disruption</b>		
Yes=1, No=0	NA	0/1
Annual Probability	NA	0.15
Maximum Length (yrs.)	NA	7
Gamma distribution parameters ( $\alpha$ , $\beta$ , offset)	NA	3.2, 3.2, 5
<b>AEO Case Probabilities (0-100)</b>		
Reference case	NA	30%
Low Oil Price Case	NA	30%
High Oil Price Case	NA	20%
High Macroeconomic Growth	NA	20%



The first simulation run uses only the AEO 2006 Reference Projection and does not include supply disruptions. It does allow uncertainties about other key parameter values shown in Table 7. It is intended to represent prospective benefits analysis that does not incorporate uncertainty about the future of world oil markets. It produces the lowest gross benefits estimates. This simulation run is not used in calculating prospective net oil security benefits. It serves as a reference point for measuring the effects of incorporating uncertainty into the analysis.

The second simulation run assumes no supply disruptions, i.e., “normal” market conditions but allows the model to randomly select among the four alternative AEO 2006 projections. The estimated mean present value gross benefits of advanced hybrid technology range from \$203 billion to \$357 billion (Table 8). These are the means; the variation in individual estimates is even greater as will be seen below. These estimates are also gross rather than net economic benefits, since no account is taken of the incremental cost of the advanced hybrid technology. Net oil security benefits are calculated as the difference between gross benefits in disrupted markets and gross benefits in normal or undisrupted markets. Thus, the incremental costs of advanced hybrid technology will be canceled since the same level of market penetration is assumed.

**Table 8. Mean Oil Security Benefits of Advanced Hybrid Vehicle Technology  
(Billions of Present Value 2004 Dollars)**

	OPEC Maintains Production	OPEC Maintains Price
	Oil Security Gross Benefits, Reference Projection Only	
Method 1	273	182
Method 2	339	224
	Oil Security Gross Benefits, No Supply Disruptions	
Method 1	296	203
Method 2	357	242
	Oil Security Gross Benefits With Supply Disruptions	
Method 1	331	261
Method 2	379	288
	Oil Security Net Benefits	
Method 1	35	58
Method 2	22	46

In general, gross benefits are greatest if OPEC does not respond to the changes in U.S. oil demand but instead maintains the original production schedule specified in the respective AEO projection. If OPEC cuts back production to maintain the AEO projection’s original oil price path, the normal market gross benefits are significantly reduced. Using method 1 (wealth transfer + potential GDP losses + disruption costs), the reduction in benefits is \$93 billion. If method 2 is used (total oil cost savings) the expected gross benefits are higher and so is the reduction in gross benefits when OPEC is assumed to maintain the price trajectory of the original AEO projection.

When supply disruptions are introduced, the oil security gross benefits of advanced hybrid technology increase. Using the recommended method 1, the oil security net benefits range from \$35 billion present value in the case where OPEC maintains its disrupted production schedule in

the face of reduced U.S. oil demand, to \$58 billion in the case in which OPEC maintains the price of oil. In disrupted scenarios, the price path OPEC attempts to maintain is the disrupted price path without the introduction of DOE's advanced technologies.<sup>21</sup>

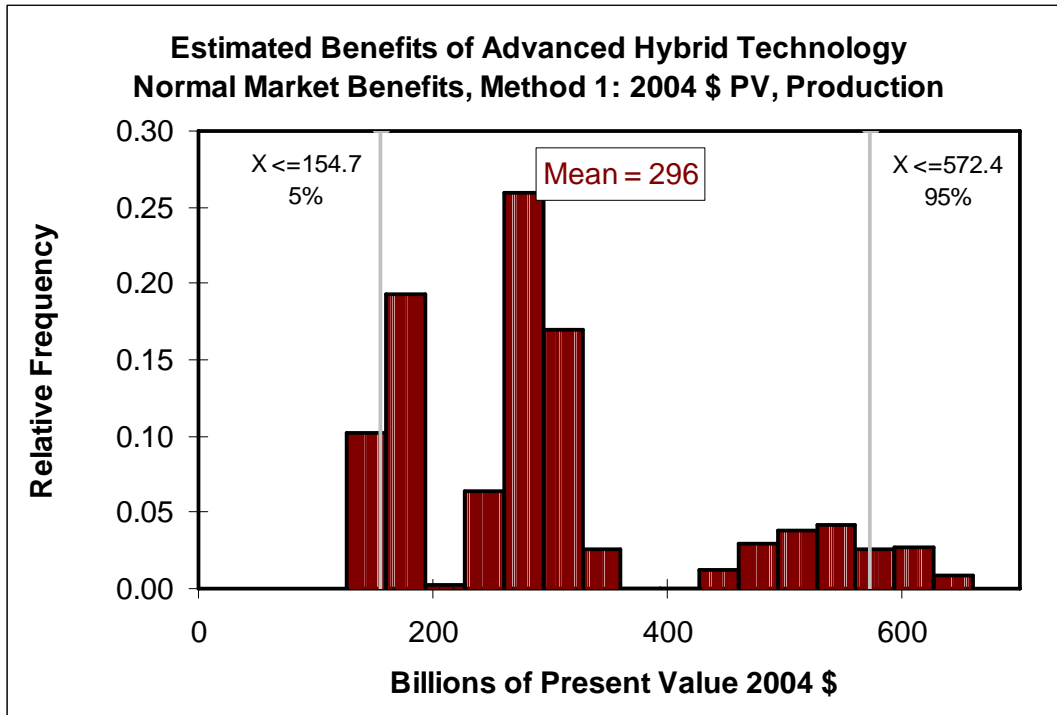
While total oil security gross benefits are greater if OPEC maintains its production schedule and allows prices to fall, oil security net benefits are greater when OPEC attempts to maintain the original price trajectory. This result suggests that oil security net benefits may be robust with respect to strategies OPEC might adopt in response to reductions in U.S. oil demand. The same pattern is evident if method 2 is used to calculate oil security net benefits: benefits are twice as large if OPEC adopts a strategy to defend the price of oil.

How world oil markets evolve will strongly influence the oil security gross benefits of advanced hybrid technology. The higher the future price of oil, the greater the gross benefits. The distribution of benefits produced by 1,000 simulations of the OSMM is tri-modal, reflecting major differences among the AEO 2006 projections. Figure 37 displays results in scenarios with no oil supply disruptions ("normal" market conditions), assuming OPEC maintains its original production schedule, and calculated using the recommended method 1. The lowest peak corresponds to the Low Oil Price projection, the highest "mound" to the High Oil Price scenario. The larger peak in the center reflects the Reference and High Growth projections, which have identical oil prices and OPEC production forecasts (Table 4). The mean gross benefits value of \$296 billion corresponds to the "Oil Security Gross Benefits, No Supply Disruptions/Method 1" cell in Table 8. The range of estimated benefits is quite large, chiefly as a result of the differences among the four AEO 2006 projections. A 95% probability interval extends from \$155 billion to \$572 billion.

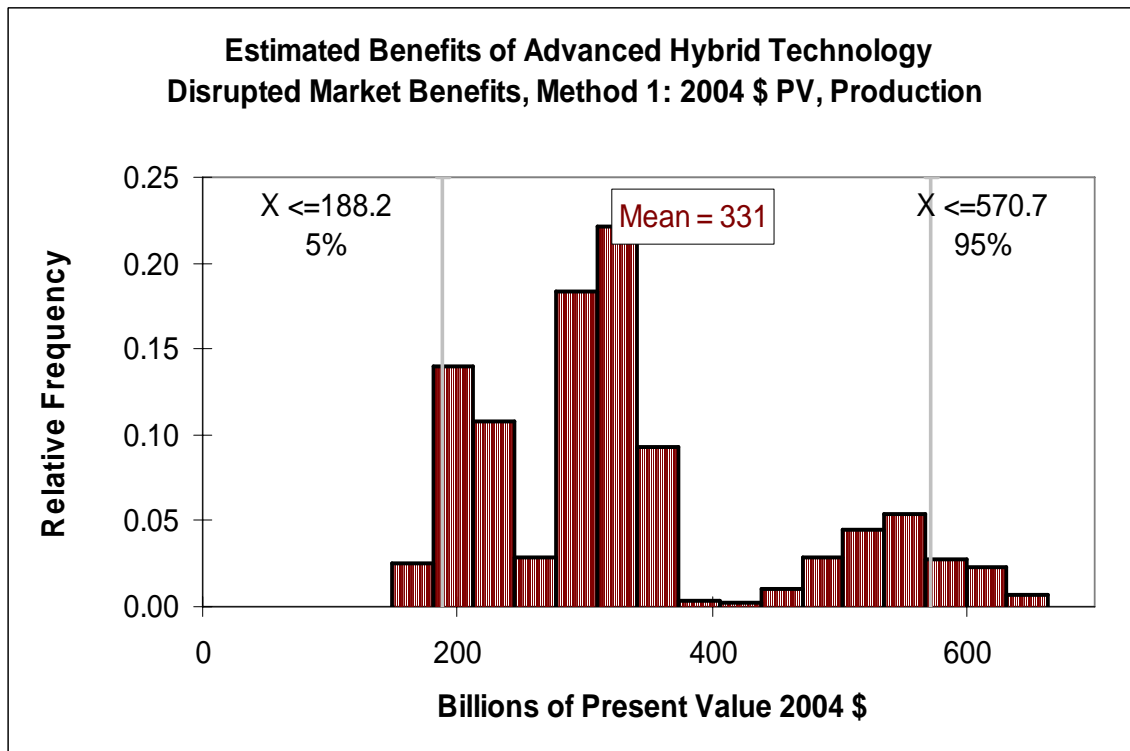
The simulations under disrupted market conditions show the same tri-modal form, but shifted upwards and compressed, with a mean value of \$331 billion and a 95% probability interval of \$188 billion to \$571 billion. It is notable that the upper confidence bound for gross benefits under disrupted market conditions is essentially the same as the upper bound for undisrupted market conditions. The implication appears to be that at oil prices in the vicinity of \$90 per barrel and with OPEC market share at about 30%, there is little scope left for further damage from oil supply disruptions of the kind simulated in the OSMM. The assumption that once OPEC's market share falls below 25%, OPEC will refrain from further supply disruptions until its share once again exceeds 25% limits OPEC's ability to disrupt oil markets.

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<sup>21</sup> If maintaining the original disrupted price path would cause OPEC's market share to fall below the specified minimum threshold, OPEC is assumed to abandon the defense of higher prices, as it did in 1986. Thus, in the disrupted scenario it is not always possible for OPEC to maintain the original price path.



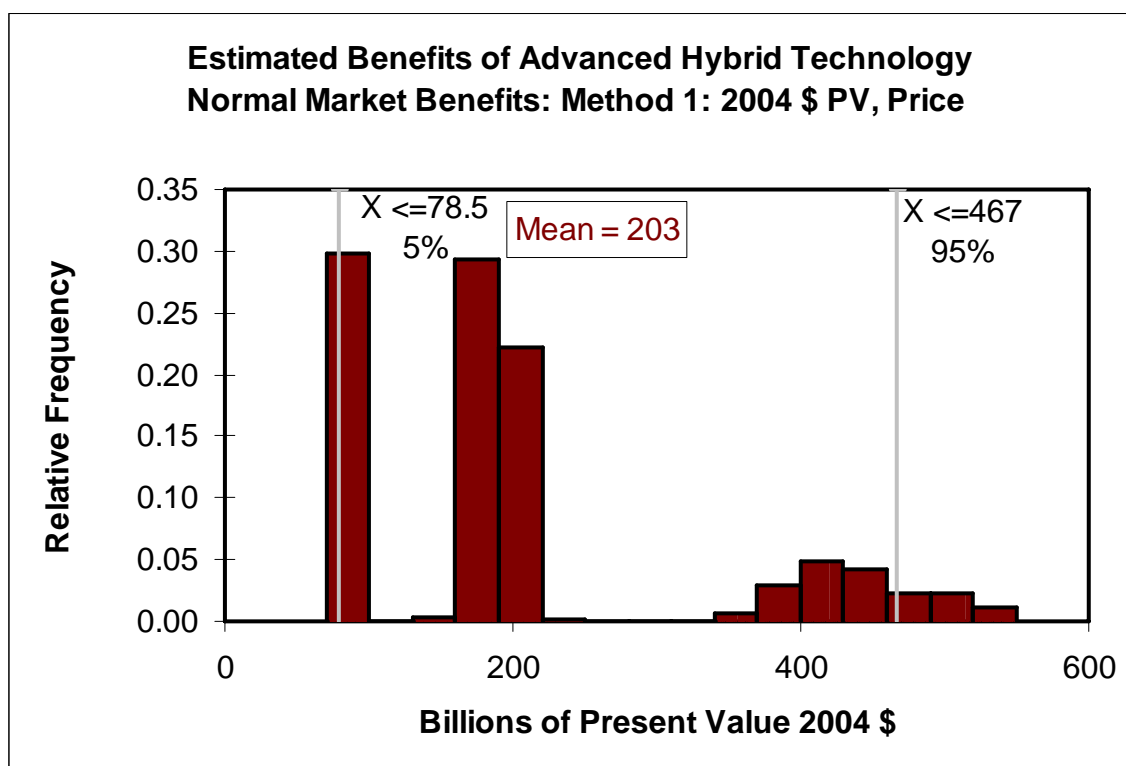
**Figure 37. Distribution of Estimated Normal Oil Market Benefits of Advanced Hybrid Technology for Light-Duty Vehicles**



**Figure 38. Distribution of Estimated Disrupted Market Benefits of Advanced Hybrid Technology for Light-Duty Vehicles**

Assuming that OPEC's response strategy is to maintain the price of oil produces lower gross benefits estimates (Figure 39). It also intensifies the tri-modality of the benefits distribution because for any given AEO projection, the price of oil will not vary among simulation runs. In the undisrupted simulations, the expected oil security gross benefit of advanced hybrid technology is \$203 billion, present value, while the 95% probability interval is \$78.5 billion to \$467 billion.

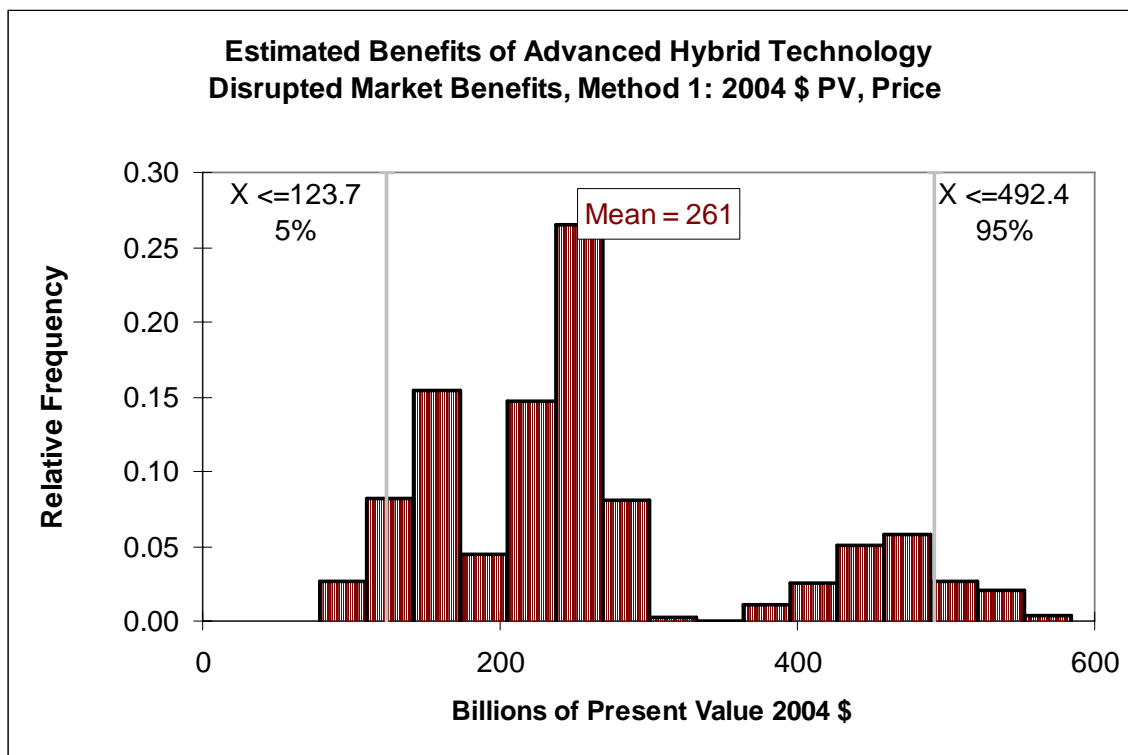
Introducing supply disruptions raises the mean gross benefit to \$261 billion and shifts the entire distribution upward. The 95% probability interval is now \$124 billion to \$492 billion. The distribution is once again compressed, as the lower boundary shifts upward almost twice as far as the upper 95% probability limit.



**Figure 39. Distribution of Estimated Normal Market Benefits of Advanced Hybrid Technology for Light-Duty Vehicles**

The results indicate three potentially significant conclusions. First, the oil security net benefits of advanced hybrid vehicle technology are likely to be large: on the order of \$40-\$50 billion present value. This applies to a single technology, aimed at the energy efficiency of light-duty vehicles only. Adding other vehicle types and introducing alternative fuels would greatly increase the estimates of prospective oil security net benefits. Second, the estimated oil security gross benefits of DOE's technology R&D increase substantially when uncertainty about the future is introduced into the analysis. Gross benefits increase when more than one scenario is used. Gross benefits increase again when price shocks are included. Benefits estimation methods that fail to reflect uncertainty about future oil market conditions will substantially underestimate the prospective benefits of DOE's R&D programs. Third, the prospective oil security net benefits of DOE's technology R&D appear to be robust to strategies OPEC might adopt to counter reductions in U.S. oil demand. In particular, if OPEC responds to reduced U.S.

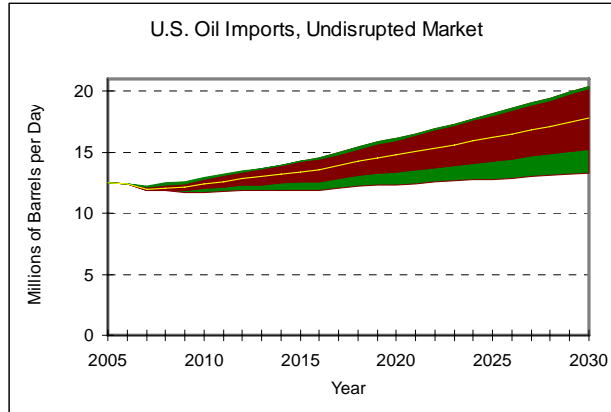
oil demand and increased price elasticity by cutting production to support a higher oil price, net security benefits *increase*.



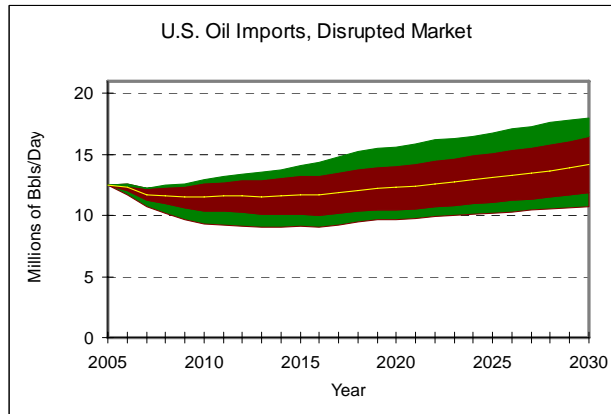
**Figure 40. Distribution of Estimated Disrupted Market Benefits of Advanced Hybrid Technology for Light-Duty Vehicles**

## 8.1 OIL SECURITY METRICS

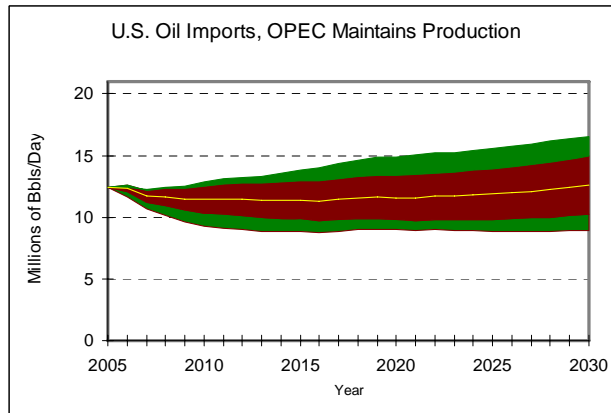
Of the 15 non-monetary oil security metrics produced by the OSMM shown in Table 3, four are illustrated in this section using the advanced hybrid vehicle technology simulation runs. The first metric considered is U.S. net imports. Figures 41a to 41d illustrate the range of U.S. imports generated under four different assumptions. The first two cases, shown in Figures 41a and 41b, illustrate oil imports in the absence of advanced hybrid vehicle technology. Figure 41a shows the probability distribution of U.S. imports over time assuming no supply disruptions but randomly selecting among the four AEO 2006 projections. The expected level of imports in 2030 is 17.8 million barrels per day, with an upper 5% probability limit of 20.2 mmbd. In the disrupted market scenario without advanced hybrid technology, the expected level of imports is 14.2 mmbd with an upper 5% value of 18.0 mmbd. The lower import levels reflect the impacts of oil supply disruptions and the higher oil prices they produce. In the presence of supply disruptions, including the impact of advanced hybrid technology, and assuming OPEC maintains the same level of production as reflected in Figure 41b, the expected level of imports falls to 12.6 mmbd with an upper 5% value of 16.5 mmbd (Figure 41c). Finally, assuming OPEC maintains the oil price path rather than its production path, the expected level of imports falls by an additional 0.5 mmbd to 12.1 mmbd, with an upper 5% value of 16.1 mmbd (Figure 41d). The advanced hybrid technology produces significant import reductions regardless of which strategy OPEC adopts.



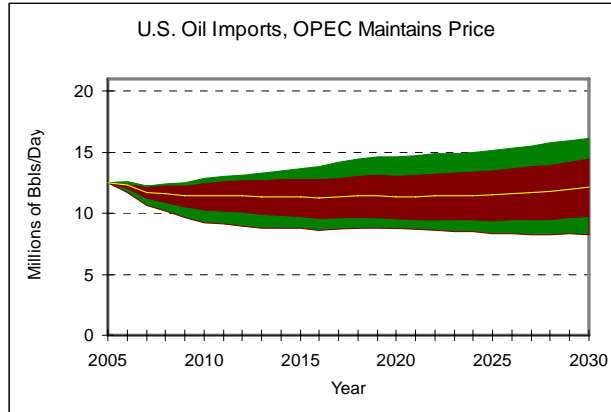
**Figure 41a. Summary Distribution of U.S. Oil Imports:  
Undisrupted Oil Market**



**Figure 41b. Summary Distribution of U.S. Oil Imports:  
Supply Disruptions**

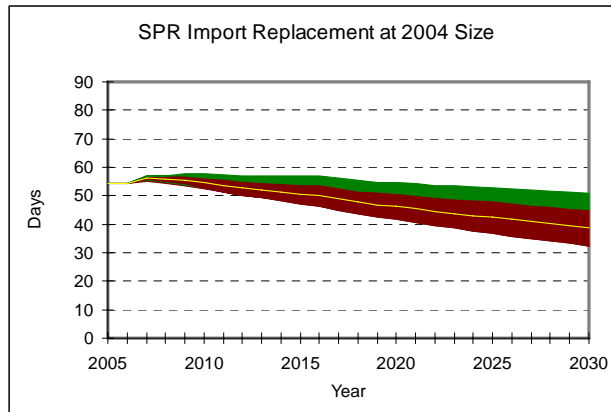


**Figure 41c. Summary Distribution of U.S. Oil Imports:  
OPEC Maintains Production**

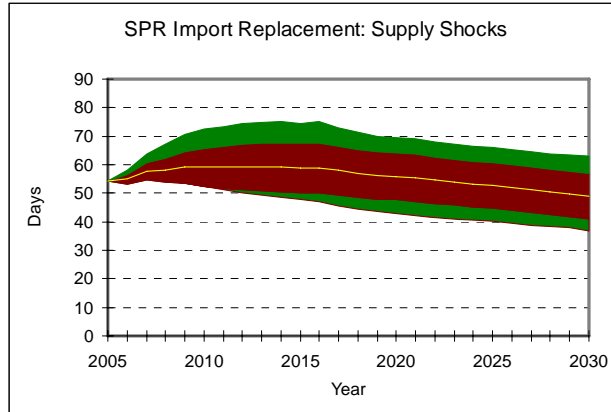


**Figure 41d. Summary Distribution of U.S. Oil Imports:  
OPEC Maintains Price of Oil**

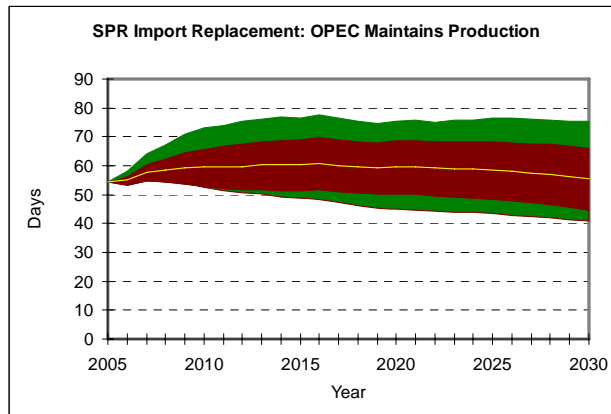
A metric closely related to net oil imports is how many days of import replacement an SPR of a given size would provide. A simulation run without oil supply shocks indicates decreasing protection from an SPR of 675.6 million barrels (the size of the SPR in 2004). The days of imports an SPR of this size could replace decreases from 54 in 2005 to an expected value of 39 days in 2030, with a 90% probability interval of 33 to 51 days (Figure 42a). Given supply shocks that raise oil prices and reduce U.S. imports, the protection afforded by a 2004-sized SPR still declines to an expected value of 49 days by 2030, but could be as little as 37 days to 63 days, with 90% probability (Figure 42b). Adding the impacts of advanced hybrid technology increases the expected level of protection to 56 days in the event that OPEC chooses to maintain production, 58 days if OPEC elects to maintain the price of oil. However, the variability in the expected level of protection also increases.



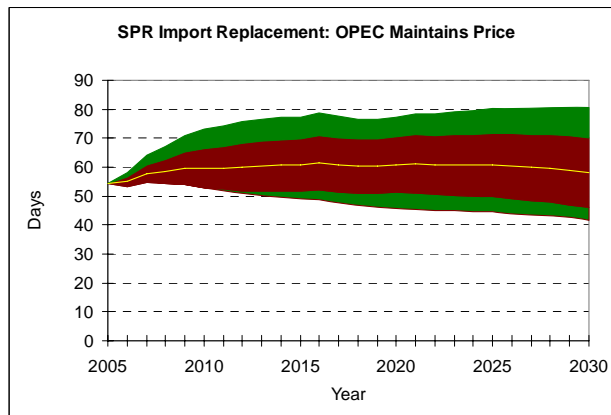
**Figure 42a. Days of Import Replacement Afforded by an SPR of  
675.6 Million Barrels: Undisrupted Oil Market**



**Figure 42b. Days of Import Replacement Afforded by an SPR of 675.6 Million Barrels: Disrupted Oil Market**



**Figure 42c. Days of Import Replacement Afforded by an SPR of 675.6 Million Barrels: OPEC Maintains Production**



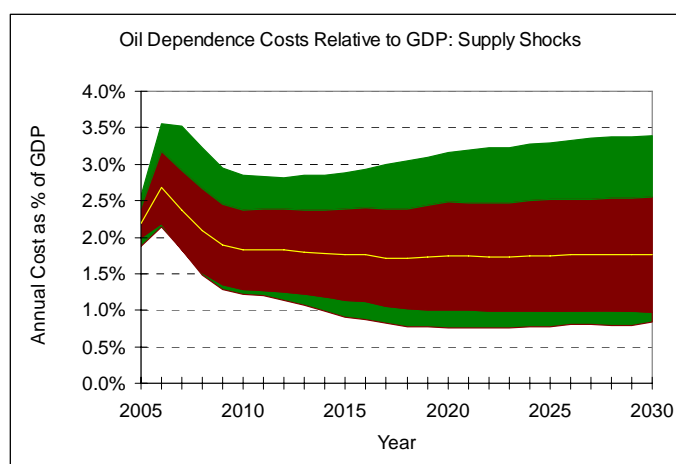
**Figure 42d. Days of Import Replacement Afforded by an SPR of 675.6 Million Barrels: OPEC Maintains Price of Oil**

Perhaps the most comprehensive indicator of U.S. oil security is total oil dependence costs (wealth transfer + surplus losses + oil supply disruption costs) relative to Gross Domestic Product (GDP). This measure could be used to define oil independence. For example, if a 90% probability interval for total oil dependence costs relative to GDP was entirely below 1%, the U.S. economy might be considered oil independent. A goal might be to achieve this by 2020 or

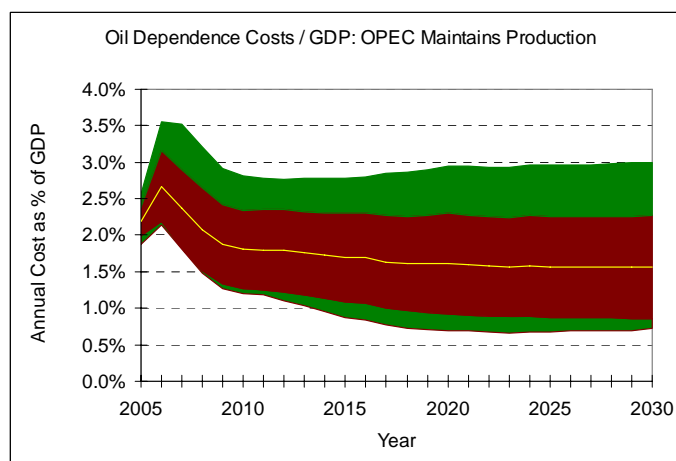


2025. The OSMM could then be used to project whether the goal is likely to be met by a given set of technologies and policies whose impacts on U.S. oil consumption, alternative fuel use and the cost of increase energy efficiency could be quantified.

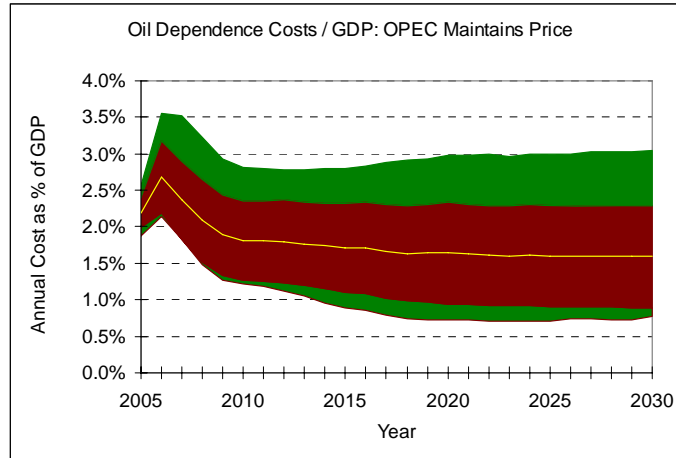
Running one thousand simulations with supply shocks but without advanced hybrid vehicle technology produces the distribution of total oil dependence costs relative to GDP shown in Figure 43a. By 2030, the expected or mean oil dependence cost relative to GDP is 1.77%, with a 90% probability interval ranging from 0.84% to 3.40%. When advanced hybrid vehicle technology and its impact on U.S. oil use is added, total oil dependence costs decline, as shown in Figures 43b and 43c. If OPEC is assumed to respond to reduced U.S. oil demand by maintaining its original (disrupted) production path, the expected dependence cost relative to GDP is 1.56% in 2030, with a 90% probability interval of 0.73% to 3.00%. If OPEC instead holds the line on oil prices, the expected cost relative to GDP is 1.59% in 2030, with a 95% probability interval of 0.77% to 3.04%. Once again, it appears that the strategy of reducing U.S. oil consumption via advanced technology is robust to OPEC responses. While the impact of advanced hybrid vehicle technology relative to GDP is modest, about 0.2%, the value in dollars is quite substantial, on the order of \$50 billion per year.



**Figure 43a. Total Annual Oil Dependence Costs Relative to GDP: Disrupted Markets**



**Figure 43b. Total Annual Oil Dependence Costs: OPEC Maintains Production**



**Figure 43c. Total Annual Oil Dependence Costs:  
OPEC Maintains World Oil Price**

A dozen other relevant metrics listed in Table 3 are produced by the Oil Security Metrics Model. These range from U.S. oil consumption to the price elasticity of U.S. oil demand, to the world oil price to OPEC revenues. Summary graphs depicting the probability distributions of these metrics over time similar to those shown above can be generated for each metric, providing a more comprehensive description of the prospective impacts of DOE's energy technology R&D on U.S. oil security.

## 9. CONCLUSIONS

A methodology has been developed for evaluating the prospective oil security net benefits of DOE's R&D programs. The methods have been implemented in the form of an Excel spreadsheet accessed and executed using the @Risk add-in software for Monte Carlo simulation. The Oil Security Metrics Model (OSMM) estimates the oil market impacts of advanced technologies and alternative fuels. It then quantifies the prospective benefits for U.S. oil security. The Monte Carlo method produces probability distributions of expected benefits that reflect uncertainties, rather than single point estimates. Uncertainty about future energy markets is represented by four alternative AEO 2006 projections. Uncertainty about oil supply shocks and prices is represented by a stochastic model of oil supply disruptions. Uncertainty about key parameters, such as price elasticities is represented by specifying them as probability distributions rather than single point estimates.

Advanced technologies resulting from DOE's R&D programs affect U.S. oil security by reducing U.S. oil consumption and by changing the price elasticity of U.S. oil demand. The price elasticity of oil demand is affected by the cost and performance of energy efficient technology and the costs and market shares of alternative fuels. The OSMM does not predict the technical success of DOE's R&D efforts, nor their market penetration, nor their impact on U.S. oil demand. These outcomes are estimated by other models. The OSMM is focused on estimating the oil security benefits of such outcomes.

The methods implemented in the OSMM are intended to be consistent with the benefits estimation framework proposed by the NRC Committee on Prospective Benefits of DOE's Energy Efficiency and Fossil Energy R&D Programs (NRC, 2005) and also with the energy security benefits framework developed by Lee (2005). Oil security net benefits are estimated in two ways. In the first and recommended approach, wealth transfer, potential GDP losses and macroeconomic disruption losses are estimated for both disrupted and normal market scenarios. The security net benefits are obtained by subtracting the normal market gross benefits from the disrupted market gross benefits.

The methodology is intended to capture the most significant oil security benefits of the DOE's Energy Efficiency and Renewable Energy R&D portfolio, including both the reduction of U.S. petroleum demand and technology-induced changes in the price elasticity of demand. Impacts on U.S. wealth as well as GDP are included. A subject for future analysis is the inclusion of Fossil Energy R&D benefits in the OSMM framework.

As an example, the model was used to estimate the oil security net benefits of advanced hybrid vehicle technology, using estimates of oil savings and cost and efficiency improvements provided by DOE/EERE.

The proposed methods do not include estimating monetary benefits for reducing military, strategic or political costs related to oil security. Future research may be able to derive economic costs for such energy security benefits, provided that a consensus can be reached on the controversial nature of these costs. In the meantime, the proposed method will produce metrics related to these costs that should be useful in qualitatively assessing the prospective benefits of EERE R&D programs.



## REFERENCES

- Adelman, M.A. 1989. "Mideast Governments and the Oil Price Prospect," *The Energy Journal*, vol. 10, no. 2, pp. 15-24.
- Atkins, F.J. and S.M.T. Jazayeri. 2004. *A Literature Review of Demand Studies in World Oil Markets*, Discussion Paper 2004-07, Department of Economics, University of Calgary, Calgary, Alberta, Canada, April.
- Austin, T.C., R.G. Dulla, T.R. Carlson, and J.S. N. Willter. 1999. "Alternative and Future Technologies for Reducing Greenhouse Gas Emissions from Road Vehicles," prepared for the Transportation Table Subgroup on Road Vehicle Technologies and Fuels, Transport Canada, Ottawa, Ontario, Canada by Sierra Research, Inc., Sacramento, California.
- Beccue, P.C. and H.G. Huntington. 2005. "An Assessment of Oil Market Disruption Risks," Final Report EMF SR 8, Energy Modeling Forum, Stanford University, Palo Alto, California, October 3, 2005.
- Berg, E., S. Kverndokk and K.E. Rosendahl. 1997. "Market Power, International CO2 Taxation and Oil Wealth," *The Energy Journal*, vol. 18, pp. 33-72.
- Brown, W.M. 1987. *Petroleum Prices: Past, Present and Prospective*, Hudson Institute, Indianapolis, Indiana.
- Cooper, J.C.B. 2003. "Price Elasticity of Demand for Crude Oil: Estimates for 23 Countries," *OPEC Review*, March, pp. 3-8.
- Copulos, M.R. 2003. "America's Achilles Heel: The Hidden Costs of Imported Oil, A Strategy for Energy Independence," National Defense Council Foundation, Washington, DC, October.
- Das, S., 2005. 2005. Personal communication supplying detailed tables to, A. Rousseau, P. Sharer, S. Pagerit and S. Das, "Trade-off between Fuel Economy and Cost for Advanced Vehicle Configurations," presented at EVS-21, the 21<sup>st</sup> Worldwide Battery, Hybrid and Fuel Cell Electric Vehicle Symposium and Exhibition, Monaco, April 2-6.
- Davis, S.C. and S.W. Diegel. 2004. *Transportation Energy Data Book Edition 24*, ORNL-6973, Oak Ridge National Laboratory, Oak Ridge, Tennessee, December.
- Delucchi, M.A. and J. Murphy. 1996. *U.S. Military Expenditures to Protect the Use of Persian-Gulf Oil for Motor Vehicles*, UCD-ITS-RR-96-3(15), Institute of Transportation Studies, University of California, Davis, April.
- Economist. 2005. "Oil in Troubled Waters: Global or National? The Perils Facing Big Oil," *The Economist*, April 30.
- Gately, D. 2004. "OPEC's Incentives for Faster Output Growth," *The Energy Journal*, vol. 25, no. 2, pp. 75-96.

Gately, D. and H.G. Huntington. 2002. "The Asymmetric Effects of Changes in Price and Income on Energy and Oil Demand," *The Energy Journal*, vol. 23, no.1, pp. 19-56.

(GAO) U.S. General Accounting Office. 1991. *Southwest Asia: Cost of Protecting U.S. Interests*, GAO/NSIAD-91-250, Washington, DC, August.

Greene, D.L. 2005. "Why Save Oil in a Hurry?" presentation to the *IEA/ECMT Workshop on Managing Oil in Transport*, International Energy Agency, Paris, March 7-9.

Greene, D.L. 1997. "Oil Dependence: the Value of R&D," Proceedings of the 32<sup>nd</sup> *Intersociety Energy Conversion Engineering Conference*, pp. 2148-2153, July 27-August 1, American Institute of Chemical Engineers, New York, NY.

Greene, D.L. and S. Ahmad. 2005. *Costs of U.S. Oil Dependence: 2005 Update*" ORNL/TM-2005/45, Oak Ridge National Laboratory, Oak Ridge, Tennessee, January.

Greene, D.L. and J. DeCicco. 2000. "Engineering-Economic Analyses of Automotive Fuel Economy Potential in the United States," *Annual Review of Energy and the Environment*, vol. 25, pp. 477-536, Annual Reviews, Palo Alto, California.

Greene, D.L. and P.N. Leiby. 1993. *The Social Costs to the U.S. of Monopolization of the World Oil Market, 1972-1991*, ORNL-6744, Oak Ridge National Laboratory, Oak Ridge, Tennessee, March.

Greene, D.L. and N.I. Tishchishyna. 2001. "Costs of Oil Dependence: A 2000 Update," *Transportation Quarterly*, vol. 55, no. 3, pp. 11-32.

Greene, D.L., J.L.Hopson and J. Li. 2005. "Running Out of and Into Oil: Analyzing Global Depletion and Transition through 2050, *Transportation Research Record 1880*, pp. 1-9, Transportation Research Board, Washington, DC.

Greene, D.L., D.W. Jones and P.N. Leiby. 1998. "The Outlook for U.S. Oil Dependence," *Energy Policy*, vol. 26, no. 1, pp. 55-69.

Greene, D.L., D.W. Jones and P.N. Leiby. 1995. *The Outlook for U.S. Oil Dependence*, ORNL-6873, Oak Ridge National Laboratory, Oak Ridge, Tennessee, May.

Griffen, J.M. and L.M. Vielhaber. 1994. "OPEC Production: the Missing Link," *The Energy Journal*, vol. 15.

Hamilton, J.D. 1996. "This is What Happened to the Oil Price-Macroeconomy Relationship," *Journal of Monetary Economics*, vol. 38, pp. 215-220.

Hamilton, J.D. and A.M. Herrera. 2001. "Oil Shocks and Aggregate Economic Behavior: The Role of Monetary Policy," Mimeo, Dept. of Economics, University of California at San Diego, July.

Hall, D.C. 1990. "Preliminary Estimates of Cumulative Private and External Costs of Energy," *Contemporary Policy Issues*, vol. VIII, no. 3, pp. 283-307.

Hickman, B.G. 1987. "Macroeconomic Impacts of Energy Price Shocks and Policy Responses: A Structural Comparison of Fourteen Models," pp. 125-198 in B.G. Hickman, H.G. Huntington and J.L. Sweeney, eds., *Macroeconomic Impacts of Energy Price Shocks*, Elsevier Science Publishers, BV, North-Holland.

Hu, P.S. 1997. "Estimates of 1996 U.S. Military Expenditures on Defending Oil Supplies from the Middle East," memorandum, Center for Transportation Analysis, Oak Ridge National Laboratory, Oak Ridge, Tennessee, August.

Huntington, H.G. 2005. "The Economic Consequences of Higher Crude Oil Prices," Final Report EMF SR 9, Energy Modeling Forum, Stanford University, Palo Alto, California, October, 3, 2005.

Huntington, H.G. 2002. "Energy Disruptions, Interfirm Price Effects and the Aggregate Economy." OP 51, Energy Modeling Forum, Stanford University, September, forthcoming in *Energy Economics*.

Huntington, H.G. 1994. "Oil Price Forecasting in the 1980s: What Went Wrong?" *The Energy Journal*, vol. 15, no. 2, pp. 1-22.

Huntington, H.G. 1991. "Inferred Demand and Supply Elasticities from a Comparison of World Oil Models," EMF WP 11.5, Energy Modeling Forum, Stanford University, Stanford, California, January.

Huntington, H.G. and J.E. Eschbach. 1987. "Macroeconomic Models and Energy Policy Issues," in B.G. Hickman, H.G. Huntington and J.L. Sweeney, eds., *Macroeconomic Impacts of Energy Shocks*, Elsevier Science Publishers, B.V., North Holland.

Huntington, H.G., J. Weyant, A. Kann and P. Beccue. 1997. "Quantifying Oil Disruption Risks through Expert Judgment," *Energy Modeling Forum Special Report 7*, Stanford University, Stanford, CA, April.

(IEA) International Energy Agency. 2001. *World Energy Outlook 2001*, OECD, Paris.

Johnston, J.B., P. Runci and J.A. Riggs. 2002. *Vulnerability and Resilience*, 2002 Aspen Energy Policy Forum, The Aspen Institute, Washington, DC.

Jones, D.W., P.N. Leiby and I.K. Paik. 2004. "Oil Price Shocks and the Macroeconomy: What Has Been Learned?" *The Energy Journal*, vol. 26, no. 2, pp. 1-32.

Kahn, J.R. 1995. *The Economic Approach to Environmental and Natural Resources*, Harcourt Brace College Publishers, New York, NY.

Kohl, W.L. 2002. "OPEC Behavior, 1998-2001," *The Quarterly Review of Economics and Finance*, vol. 42, pp. 209-233.

Lee, K., S. Ni and R.A. Ratti. 1995. "Oil Shocks and the Macroeconomy: The Role of Price Variability," *The Energy Journal*, vol. 16, no. 4, pp. 39-56.

Lee, Russell. 2005. "Metrics for Gauging the Energy Security Benefits of Energy Technology R&D Programs: Framework and Approach," draft report, Oak Ridge National Laboratory, Oak Ridge, Tennessee, April.

Leiby, P.N. and D. Bowman. 2000. *The Value of Expanding the U.S. Strategic Petroleum Reserve*, ORNL/TM-2000/179, Oak Ridge National Laboratory, Oak Ridge, Tennessee, November.

Lempert, R.J., S.W. Popper and S.C. Bankes. 2003. *Shaping the Next One Hundred Years: New Methods for Quantitative, Long-Term Policy Analysis*, Rand Publishing, New York.

Lynch, D.J. 2005. "Some Oil Money Is Up to No Good," *USA Today*, August 23.

Maass, P. 2005. "The Breaking Point," *The New York Times*, Magazine, August 21.

Moore, J.L., C. E. Behrens, and J. E. Blodgett. 1997. "Oil Imports: An Overview and Update of Economic and Security Effects," Congressional Research Service, Environment and Natural Resources Policy Division, Report 98-1, December 12.

Morison, M.B. 1987. "The Price of Oil: Lower and Upper Bounds," *Energy Policy*, vol. 15, no. 5, pp. 399-407.

Mork, K.A. 1989. "Oil and the Macroeconomy when Prices Go Up and Down: An Extension of Hamilton's Results." *Journal of Political Economy*, vol. 97, pp. 740-744.

(NEPDG) National Energy Policy Development Group. 2001. *National Energy Policy*, Report to the President of the United States, Washington, DC, May 16.

(NRC) National Research Council. 2005. *Prospective Evaluation of Applied Research and Development at DOE (Phase One): A First Look Forward*, Committee on Prospective Benefits of DOE's Energy Efficiency and Fossil Energy R&D Programs, National Academy Press, Washington, DC.

(NRC) National Research Council. 2002. *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards*, National Academy Press, Washington, DC.

(NRC) National Research Council. 2001. *Energy Research at DOE: Was It Worth It?* Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy, National Academy Press, Washington, DC.

(NRC) National Research Council. 1992. *Automotive Fuel Economy: How Far Should We Go?* National Academy Press, Washington, DC.



Palisade Corporation. 2002. *@Risk Advanced Risk Analysis for Spreadsheets*, Version 4.5, February, 2002, Newfield, NY, [www.palisade.com](http://www.palisade.com).

Parry, I.W.H. and J.W. Anderson. 2005. "Petroleum: Energy Independence is Unrealistic," *Resources*, pp. 11-15, issue no. 156, Winter 2005, Resources for the Future, Washington, DC.

Plotkin, S., D. Greene and K.G. Duleep. 2002. *Examining the Potential for Voluntary Fuel Economy Standards in the United States and Canada*, ANL/ESD/02-5, Center for Transportation Research, Argonne National Laboratory, Argonne, Illinois, October.

Priddle, R. 2002. "A New Perspective on Energy Security," *International Association for Energy Economics Newsletter*, pp. 12-13, Energy Economics Education Foundation, Inc., Cleveland, Ohio.

Rotemberg, J.J. and M. Woodford. 1996. "Imperfect Competition and the Effects of Energy Price Increases on Economic Activity," *Journal of Money, Credit and Banking*, vol., 28, pp. 549-577.

Santini, D.J. 1999. "The Petroleum Problem: The Tip of Another Iceberg," presented at the *U.S. Association for Energy Economics/International Association for Energy Economics 20<sup>th</sup> Annual North American Conference*, Orlando, Florida, August 29-September 1.

Santini, D.J. 1994. "Verification of Energy's Role as a Determinant of U.S. Economic Activity," *Advances in the Economics of Energy and Resources*, vol. 8, pp. 159-194.

Schock, R., W. Fulkerson, M.L. Brown, R.L. San Martin, D.L. Greene and J. Edmonds. 1999. "How Much is Energy Research & Development Worth as Insurance?" *Annual Review of Energy and the Environment*, vol. 24, pp. 487-512.

Sierra Research. 1999. "Alternative and Future Technologies for Reducing Greenhouse Gas Emissions from Road Vehicles," Sierra Research, Inc., Sacramento, California, July 8.

Singh, M. 2006. Personal communication, January 5, providing VISION model results, Argonne National Laboratory, Washington, DC.

Singh, M. 2006. Personal communication, January 5, providing VISION model results, Argonne National Laboratory, Washington, DC.

Singh, M, A. Vyas and E. Steiner. 2003. "VISION Model: Description of Model Used to Estimate the Impact of Highway Vehicle Technologies and Fuels on Energy Use and Carbon Emissions to 2050," Argonne National Laboratory, Argonne, Illinois.

Smith, J.L. 2005. "Inscrutable OPEC? Behavioral Tests of the Cartel Hypothesis," *The Energy Journal*, vol. 26, no. 1, pp. 51-82.

Sugden, R. and A. Williams. 1980. *The principles of practical cost-benefit analysis*, Oxford University Press, Oxford, UK.

Suranovic, S.M. 1994. "Import Policy Effects on the Optimal Oil Price," *The Energy Journal*, vol. 15, no. 3, pp. 123-144.

Taylor, J. and P. VanDoren. 2001. "Oil Weapon Myth," *National Review Online*, December 6, <http://www.cato.org/research/articles/taylor-011206.html> .

Toman, Michael A. 2002. "International Oil Security Problems and Policies," *The Brookings Review*, 20(2):20-23, Spring.

(U.S. DOE/EIA) U.S. Department of Energy, Energy Information Administration. 2006. *Annual Energy Outlook 2006*, DOE/EIA-0383(2006), Washington, DC, February.

(U.S. DOE/EIA) U.S. Department of Energy, Energy Information Administration. 2005. "Short Term Energy Outlook – February 2005," <http://www.eia.doe.gov/emeu/steo/pub/steo.html>.

(U.S. DOE/EIA) U.S. Department of Energy, Energy Information Administration. 2001. *A Primer on Gasoline Prices*, DOE/EIA-X040(2001), Washington, DC, April.

von Stackelberg, H. 1952. *The Theory of the Market Economy*, Oxford University Press, New York, NY.

Wells, Jim. 2005. *Meeting Energy Demand in the 21<sup>st</sup> Century: Many Challenges and Key Questions*, GAO-05-414T, Testimony before the Subcommittee on Energy and Resources, Committee on Government Reform, House of Representatives, U.S. Government Accountability Office, Washington, DC.

Wirl, F. 1990. "Dynamic Demand and Optimal OPEC Pricing," *Energy Economics*, vol. 12, no. 3, pp. 174-177.

Yergin, D. 1992. *The Price*, Simon & Schuster, New York.

Zakaria, F. 2005. "How to Escape the Oil Trap," *Newsweek*, August 29, 2005, <http://www.msnbc.com/id/9024768/site/newsweek/print/1/displaymode/1098/> .



**APPENDIX**

**OIL SUPPLY AND DEMAND ELASTICITIES**



## APPENDIX

### OIL SUPPLY AND DEMAND ELASTICITIES

Several recent studies imply that U.S. oil supply and demand elasticities may be slightly greater than assumed in our previous reports. Price elasticities of oil demand from a number of recent studies were evaluated by Atkins and Jazayeri (2004). These are summarized in Table B-1. The short-run price elasticity estimates had a mean value of -0.052 and a median of -0.05. The long-run estimates showed much greater variability, but with a mean and median of -0.36 and -0.32, respectively. Assuming a linear lagged adjustment demand equation, these imply mean and median adjustment rates of 0.86 and 0.84, respectively.

**Table B-1. Recent Estimates of the Price Elasticity of Oil Demand**

Author	Short-Run	Long-Run	Adjustment Rate	Region
Kalymon (1975)	--	-0.5	--	various
Brown and Philips (1980)	-0.08	--	--	
Dahl (1993)	-0.05 to -0.09	-0.16 to -0.23	0.6 to 0.7	various
Peseran, et al. (1998)	-0.03	-0.48	0.9	
Gately & Huntington (2002)	-0.05	-0.59 to -0.64	0.9	OECD
Gately & Huntington (2002)	-0.03	-0.16 to -0.27	0.8 to 0.9	non-OECD
Cooper (2003)	0.0 to -0.11	0.0 to -0.53	0.8	23 countries
Cooper (2003)	-0.024 to -0.069	-0.18 to -0.45	0.8 to 0.9	G-7
Hunt & Ninomiya (2003)	--	-0.08 to -0.12	--	Japan, UK

Source: Cooper (2003)

Greene, Jones and Leiby (1995) found a range of estimates of short-run demand elasticities of -0.027 to -0.116, with a mean of -0.070 and a median value of -0.062. Long-run elasticities ranged from -0.16 to -2.5, with mean and median values of -0.65 and -0.54, respectively. Adjustment rates varied widely, from 0.58 to 0.99 (associated with the long-run elasticity of -2.5). The mean and median values imply an adjustment rate of 0.89. These estimates were based on oil prices averaging approximately \$35 per barrel (2000 \$).

Gately and Huntington (2002) compared constant elasticity demand models with models that allowed different responses to price increases and decreases. They estimated separate models for OECD and non-OECD countries. For OECD countries, the short-run elasticity of their constant elasticity model was -0.05, while their asymmetric model indicated an elasticity of -0.04 for price decreases and -0.08 for increasing prices. Tests indicated that the asymmetric model was significantly better than the constant elasticity model. The lagged adjustment coefficient estimates ranged from 0.88 to 0.91, suggesting long-run elasticities approximately ten times as large as the short-run values. Long-run elasticities were -0.59 for the constant elasticity model and -0.64 to -0.71 for two versions of the asymmetric model. Elasticities for non-OECD countries were smaller: -0.03 for the short-run elasticity in the constant elasticity model, +0.04 to -0.05 in the asymmetric model, which was not consistently a superior formulation for non-OECD countries. Lagged adjustment coefficient estimates were 0.82 to 0.84, and long-run elasticity estimates ranged from -0.16 to -0.27.

Less information is available concerning the price elasticity of oil supply. Huntington (1991) reviewed estimates of the price elasticity of oil supply outside of OPEC (Table B-2). He found that short-run elasticity estimates were considerably less than +0.1, averaging +0.03 for total non-OPEC supply and +0.05 for the United States and other OECD countries. In his simulation modeling, Huntington (1994) chose a value of +0.4 for the long-run price elasticity of oil supply and an adjustment rate of 0.9, implying a short-run elasticity of +0.04. Gately (2004) assumed a short-run, non-OPEC oil supply elasticity of between 0.03 and 0.05 in his analysis of OPEC's incentives to expand production capacity. His long-run supply elasticity estimates ranged from 0.15 to 0.58, implying adjustment rates between 0.80 and 0.91.

**Table B-2. Estimates of the Elasticity of U.S. Oil Supply**

Model/Source	Short-Run	Long-Run	
EIA	0.117	0.34	0.66
Gately	0.045	0.577	0.92
CERI	0.137	0.195	0.30
HOMS	0.012	0.522	0.98
FRB Dallas	0.013	0.475	0.97
HOMS-I	0.0859	0.662	0.87
Average	0.068	0.462	0.85

Source: Huntington, 1991, table A.3.

Linear lagged adjustment equations are used to represent U.S. oil demand and supply for purposes of calculating losses of potential GDP. The linear form implies that price elasticities are not constant over time, but vary with the price of oil and quantities consumed and produced.

$$Q_t = \lambda a + \lambda b P_t + (1 - \lambda) Q_{t-1}$$

$$\frac{\partial Q}{\partial P} \frac{P}{Q} = \lambda b \frac{P}{Q}$$

(B-1)

The price elasticities given above are assumed to apply at the average price of oil over the period 1970-2004, \$28/bbl, and the average quantities of U.S. demand (17.5 mmbd) and supply (10.2 mmbd). Based on the evidence presented above, the short-run price elasticity of U.S. oil demand is assumed to be -0.06 at the average price of oil since 1971 (\$28/bbl) and the average level of U.S. demand (17.45 mmbd). The short-run elasticity of supply is assumed to be +0.05 at the same price and at the average U.S. oil production for 1971-2004 of 10.24 mmbd). The adjustment rates are assumed to be 0.85 for demand and supply ( $\lambda = 0.15$ ), so that the long-run elasticities are -0.4 and +0.33, again at \$28/bbl. More elastic supply and demand implies larger potential GDP losses.